Overflow Juncture Flow Computations Compared with Experimental Data

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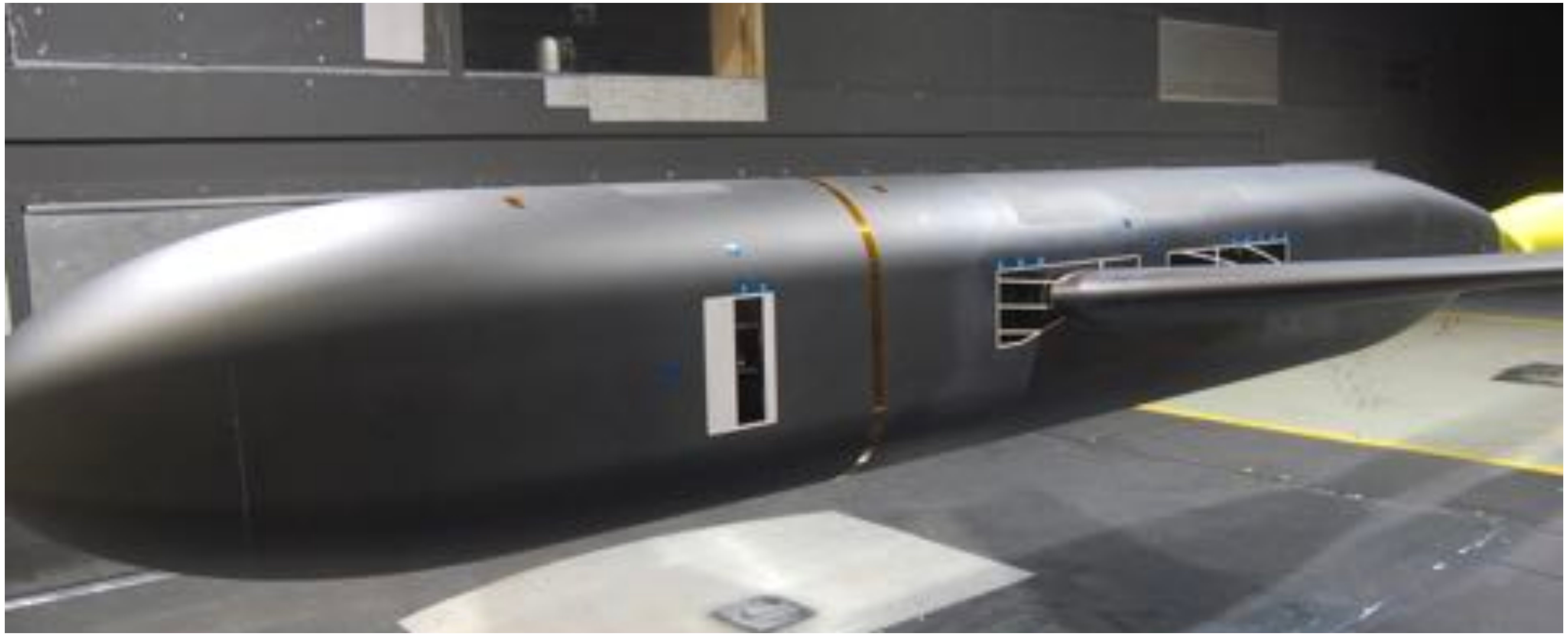
Juncture Flow Experiment

Sponsored by NASA's Transformative Aeronautics Concepts Program's
Transformational Tools and Technologies (T^3) project

- Substantial effort to investigate the origin of separation bubbles found in wing-body juncture zones
- Primary goal is to gather validation level data, for future CFD code & turbulence model development
- Multi-year effort including several large-scale wind tunnel tests
  - First set of entries just finished: Nov 2017-April 2018
  - Planned Entries in the future



Juncture Flow Experiment

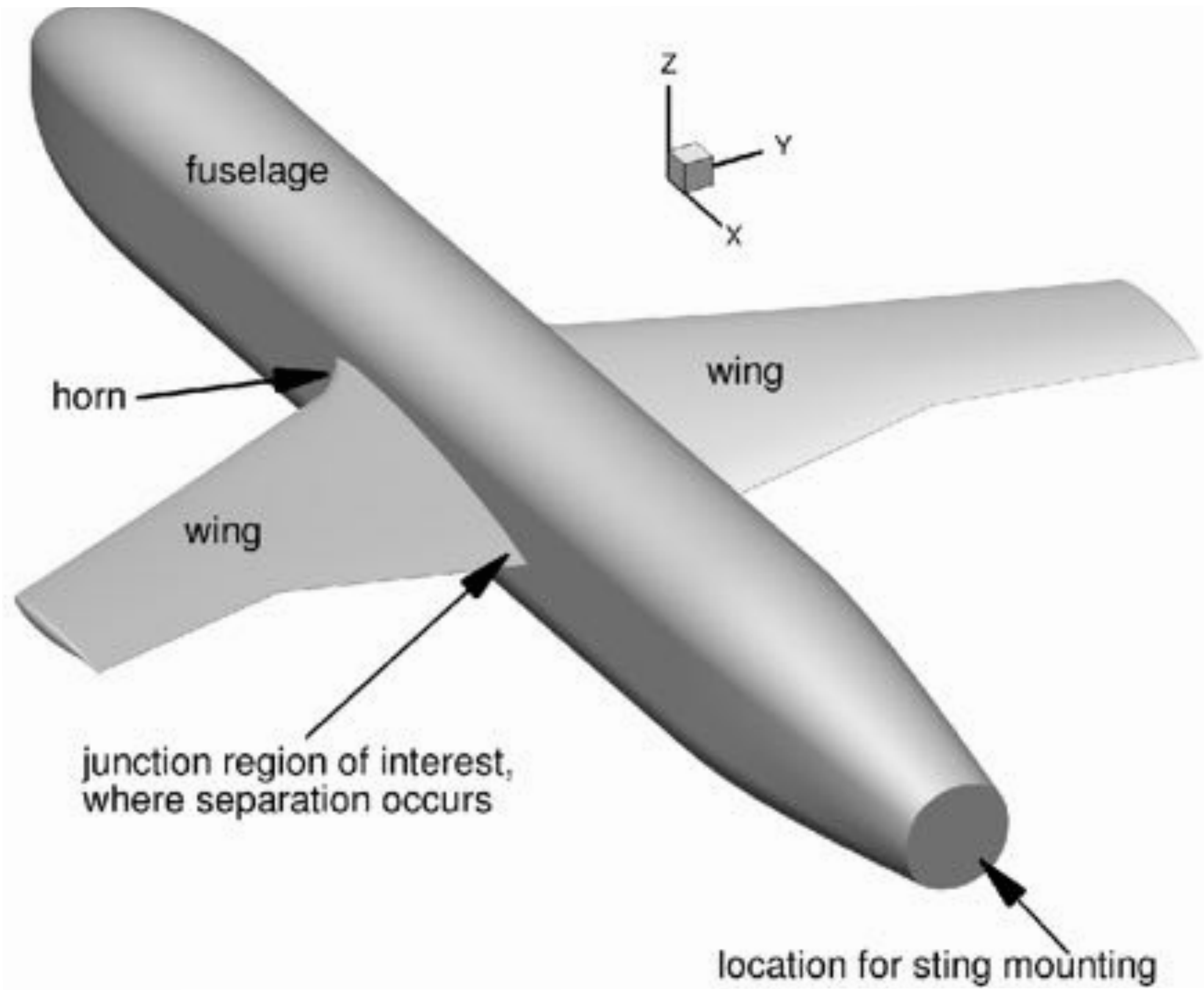
- Heavy collaboration: CFD and WT design team
  - CFD used extensively in the experiment design
  - Companion CFD runs for all risk assessment experiments
- Publications:
  - AIAA 2016-1557, AIAA 2016-1558, AIAA 2017-4127, AIAA 2017-4126, NASA TM-2016-219348, STO-MP-AVT-284-02

- Have experimental data now, how well does CFD RANS (OVERFLOW) do?

OVERFLOW Approach

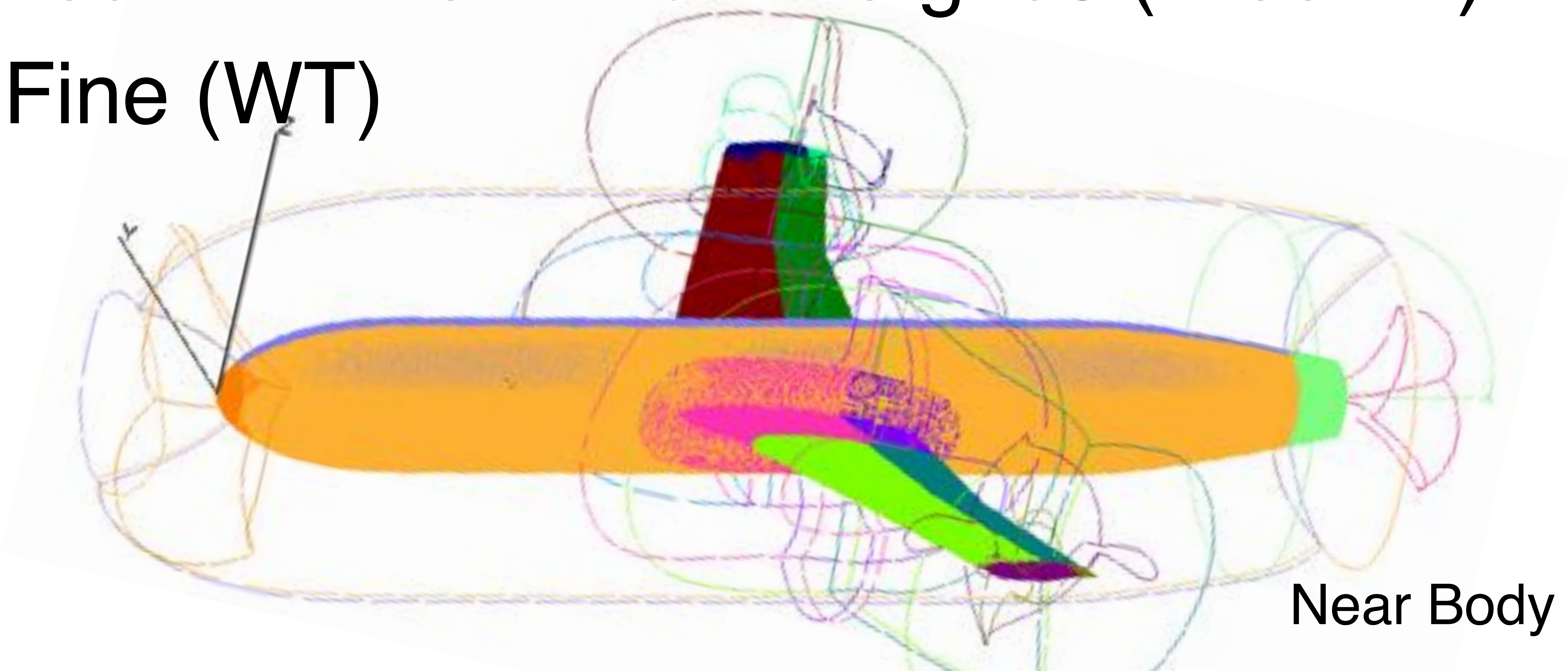
- Similar data analysis to prior talk (Chris Rumsey & FUN3D)
- OVERFLOW CFD RANS current “state of the art” evaluation
  - Grid Resolution (in Free Air)
  - Wall Effect, Free Air vs WT walls
  - Turbulence Model (in Free Air)

- Data Comparisons
  - Separation Size
  - Wing Pressure (cuts)
  - Surface Streamlines
  - Velocity Profiles
  - Reynolds Stress Profiles



OVERFLOW Grids

- Structured overset grid system
  - Free Air: Curvilinear near-body, Cartesian off-body
  - WT: Curvilinear near-body, Curvilinear wind tunnel wall grids
- Grid family created using guidelines from DPW series
  - Coarse-Medium-Fine-Extra Fine grids (Free Air)
  - Medium-Fine (WT)



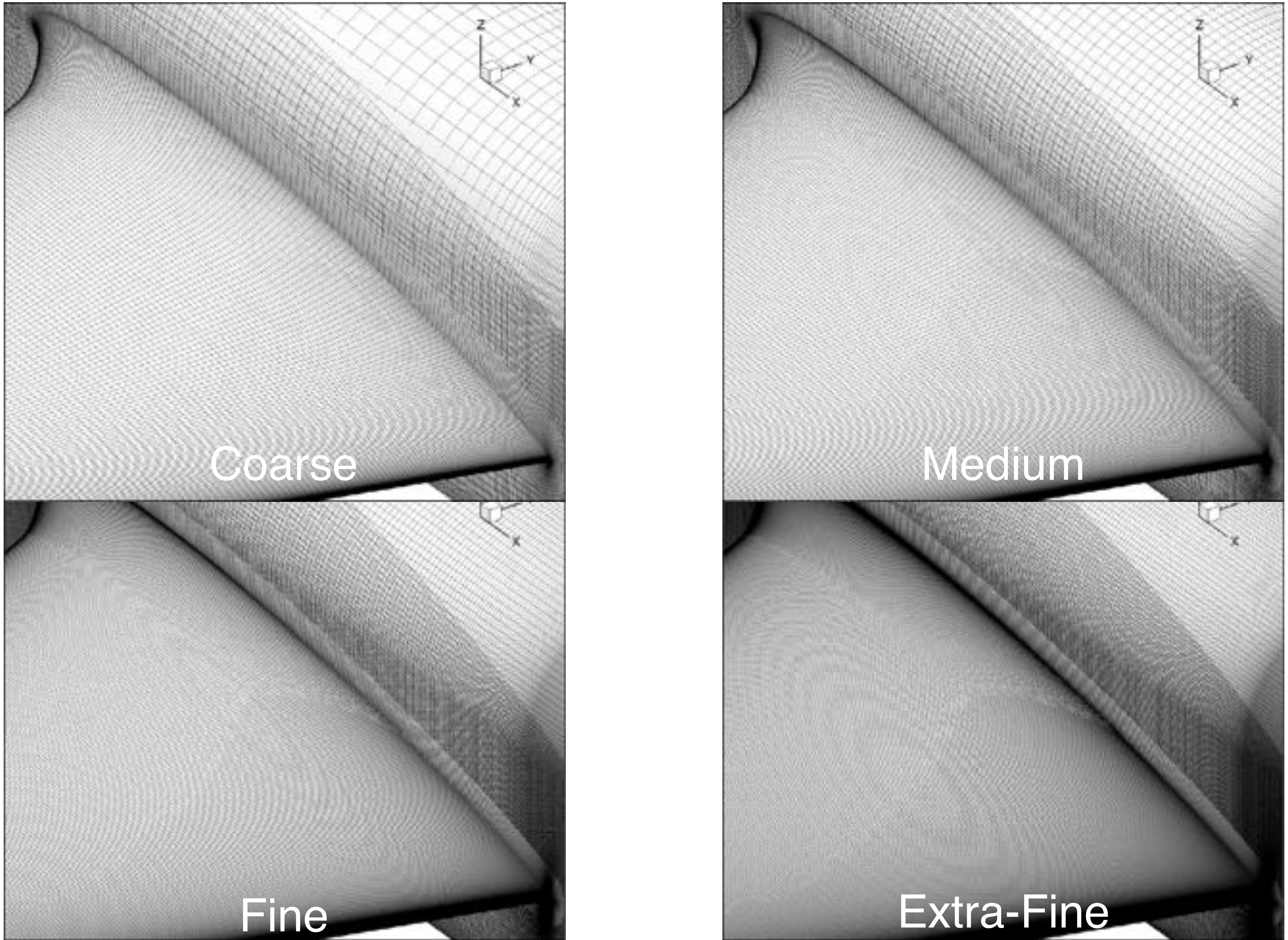
Near Body Grids

OVERFLOW Grid Parameters

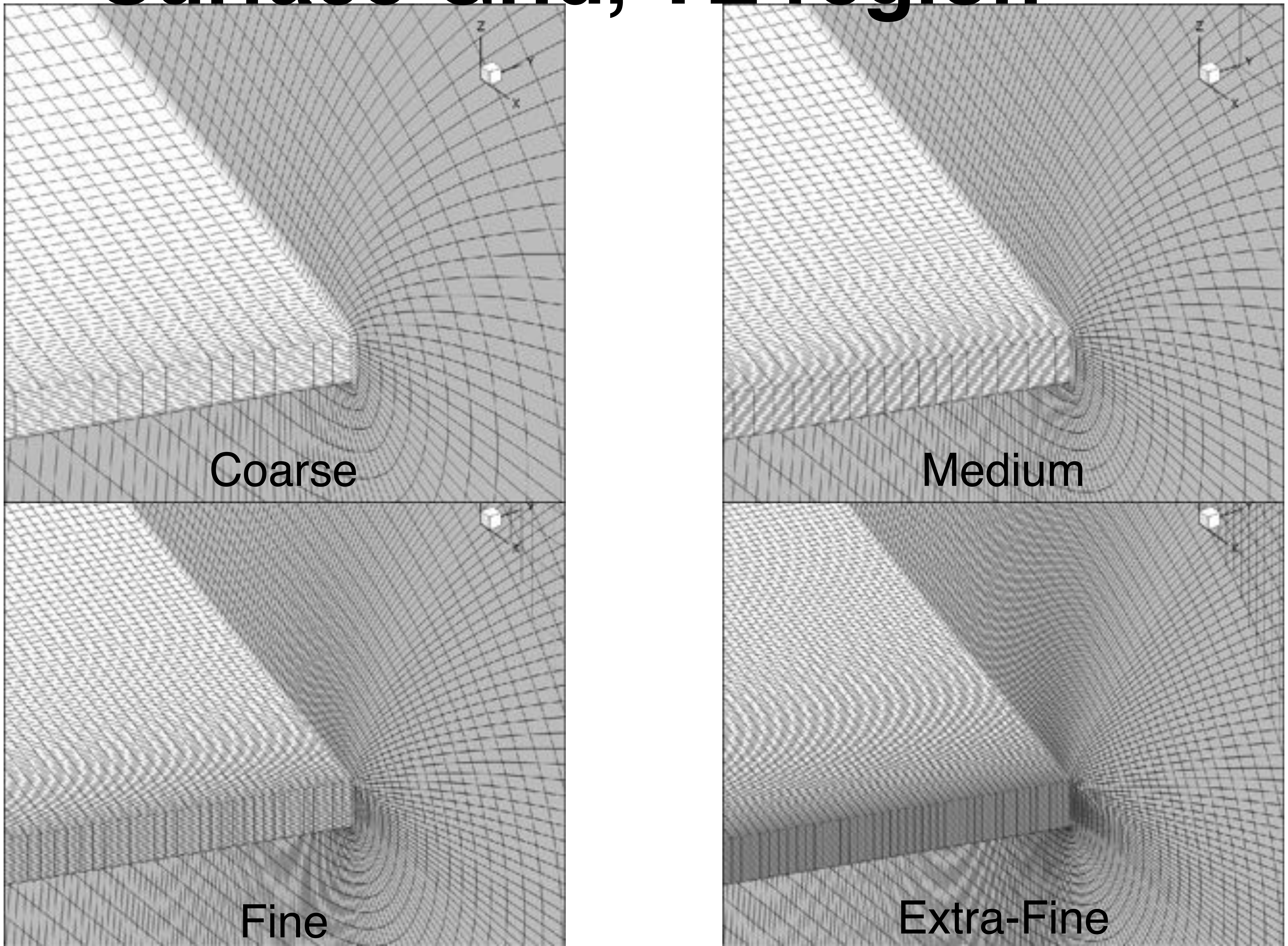
Same Near Body Grids

Configuration	Stretching Ratio	Near Body Grid Points	Total Grid Points
Free Air Coars		19.4M	21.4M
Free Air Medium	1.15	47.6M	48.7M
Free Air Fine	1.10	163.6M	165.7M
Free Air Extra-Fine	1.08	382.1M	398.4M
Wind Tunnel Medium	1.15	47.6M	92.6M
Wind Tunnel Fine	1.10	163.6M	325.5M

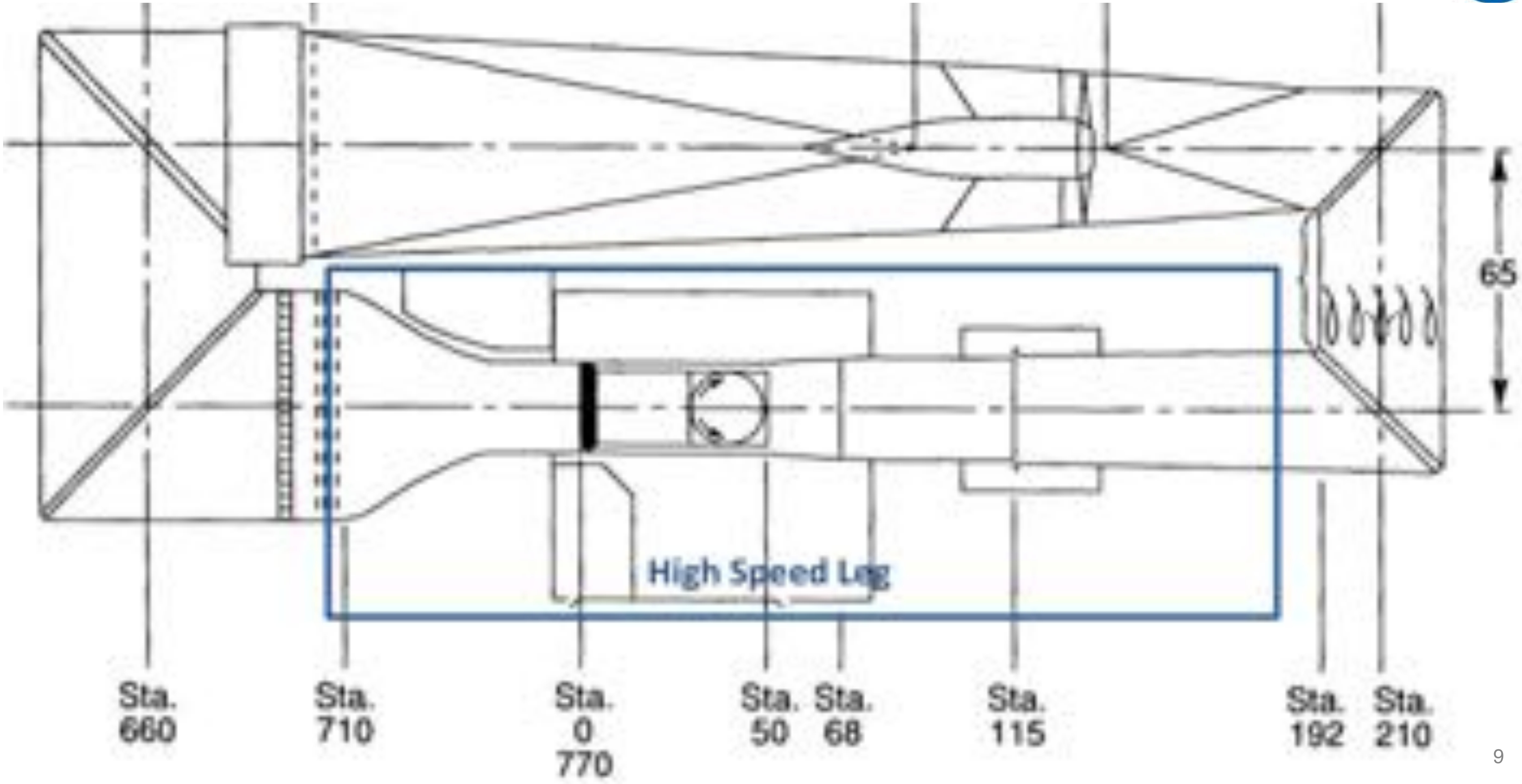
Surface Grid



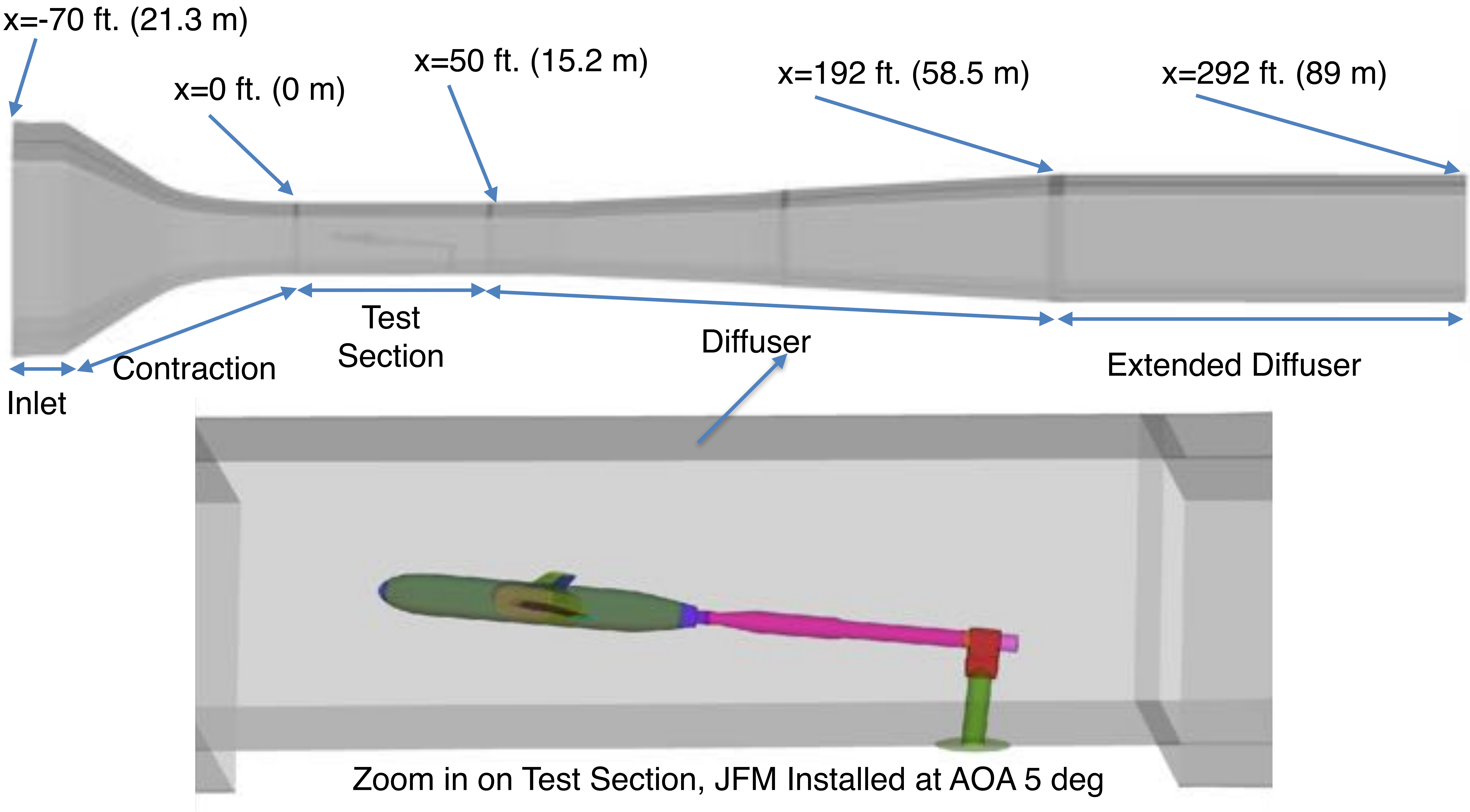
Surface Grid, TE region



Langley 14- by 22-Ft. Subsonic Tunnel (14x22)

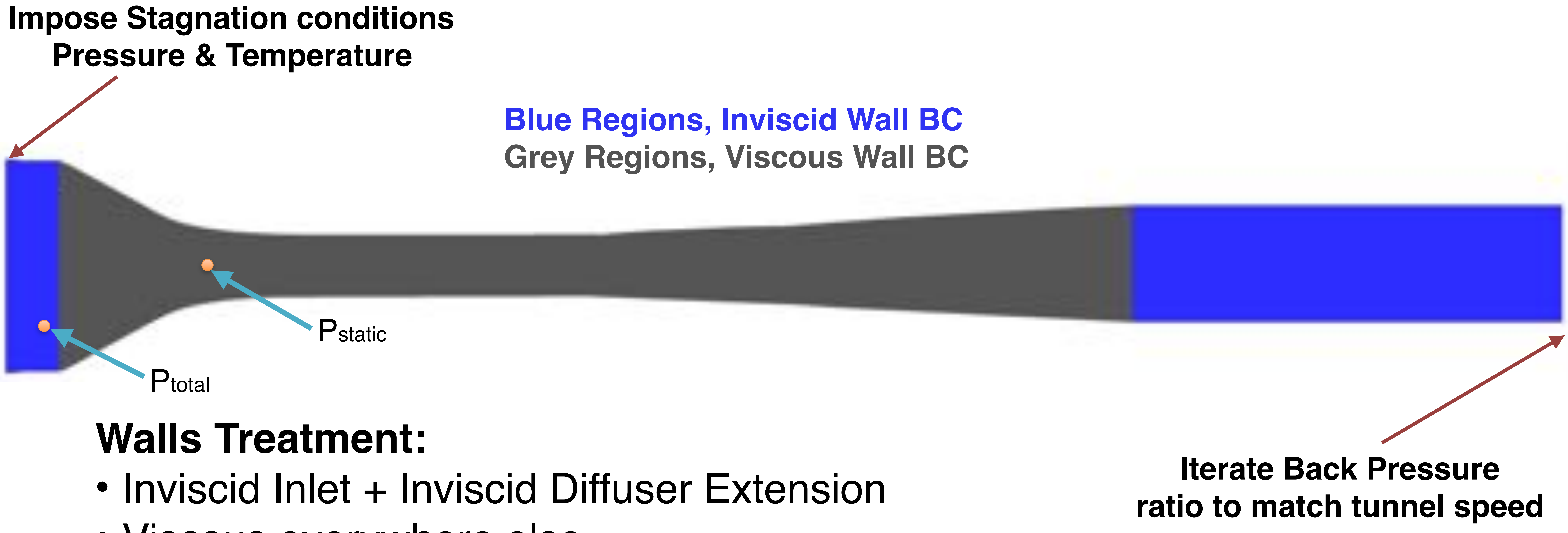


CFD 14x22 Wind Tunnel



Zoom in on Test Section, JFM Installed at AOA 5 deg

CFD 14x22 Wind Tunnel Setup



Walls Treatment:
- Inviscid Inlet + Inviscid Diffuser Extension
- Viscous everywhere else

Tunnel speed:
- Uses total pressure & static pressure "probe" values from their locations
- Calibrated equations -> tunnel speed
- Ref: Lee, et.al. STO-MP-AVT-284-02

Overflow Run Parameters

- OVERFLOW 2.2n
- 3rd-Order Roe upwind RHS
- ARC3D scalar pentadiagonal LHS
- Low-Mach preconditioning (in CFD WT)
- Fully Turbulent, Steady State
- RE = 2.4 Million based on crank chord
- Mach= 0.189, T= 519 Rankine (288.8 Kelvin) (median of run conditions)
- Turbulence Models:
  - SA-Noft2-RC-QCR2013 (SARC-QCR)
  - SA-Noft2-RC (SARC)
  - SST-RC-QCR2013 (SSTRC-QCR)

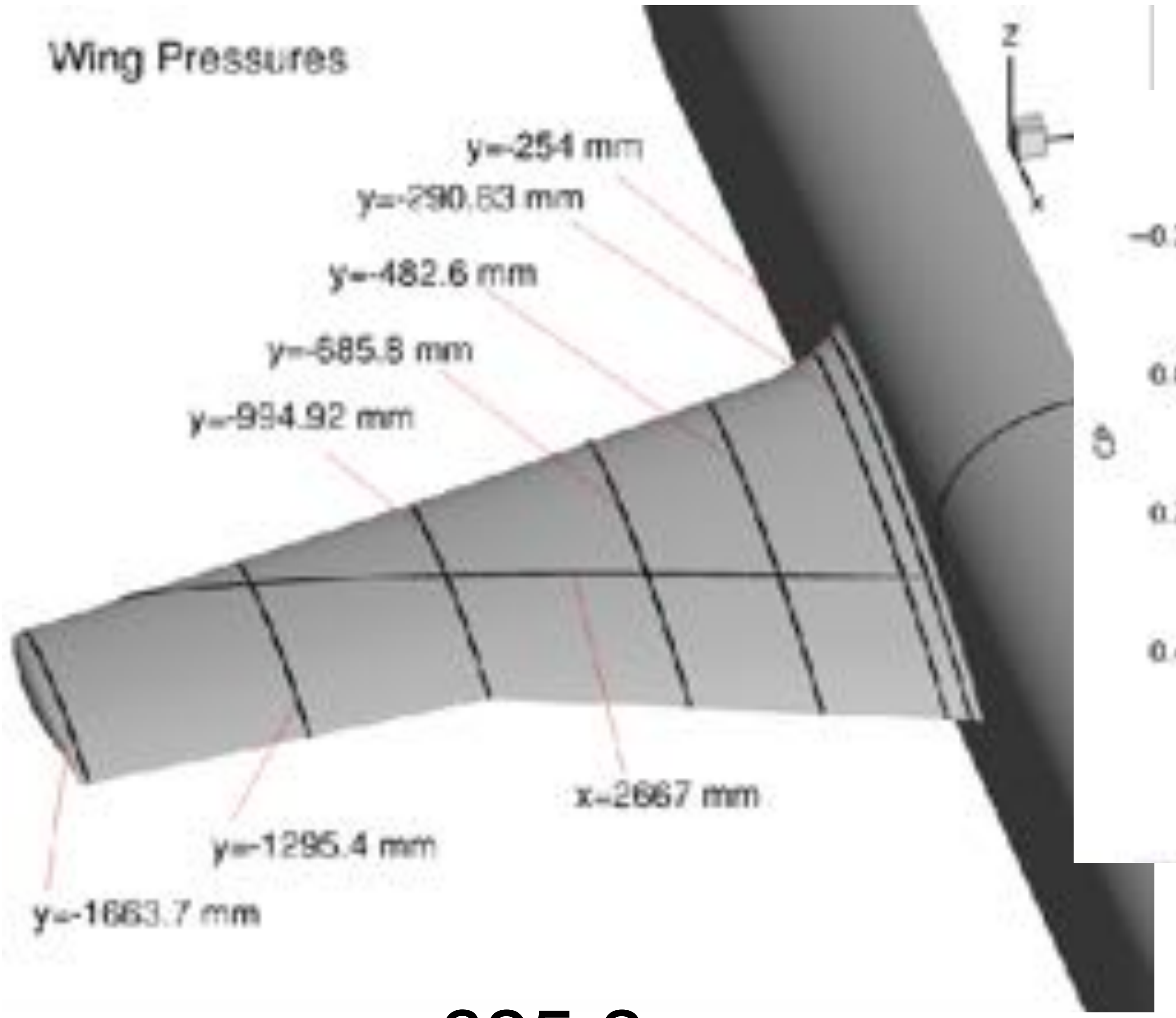
Side of Body Separation AOA = 5.0 deg

Side o … eg

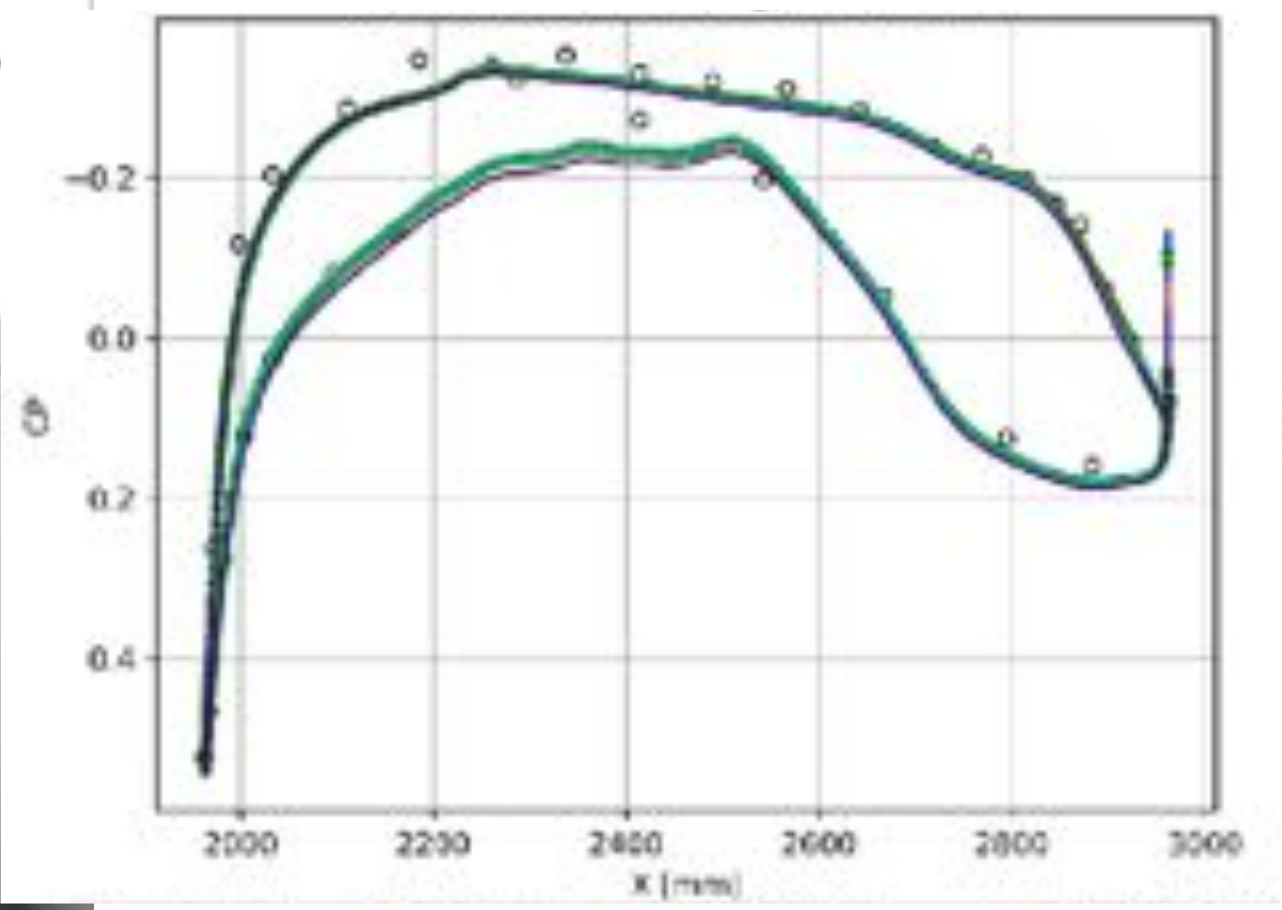
Alpha = -2.5
Medium Grid
Free Air
Wind Tunnel / Sting-Mast
Fine Grid
Free Air
Wind Tunnel / Sting-Mast
Extrafine Grid
xp -2.5
FD Air SARC-QCR
FD Air SARC
FD Air SSTRC-QCR
FD WT SARC-QCR
Length [mm]
Width [mm]
Near Body Grid Points$^{-2/3}$
Near Body Grid Points$^{-2/3}$
300
250
200
150
100
50
0
60
40
20
0
0
5E-06
1E-05
1.5E-05
2E-05
0
5E-06
1E-05
1.5E-05
2E-05

Wing Pressures, AOA = 5.0 deg

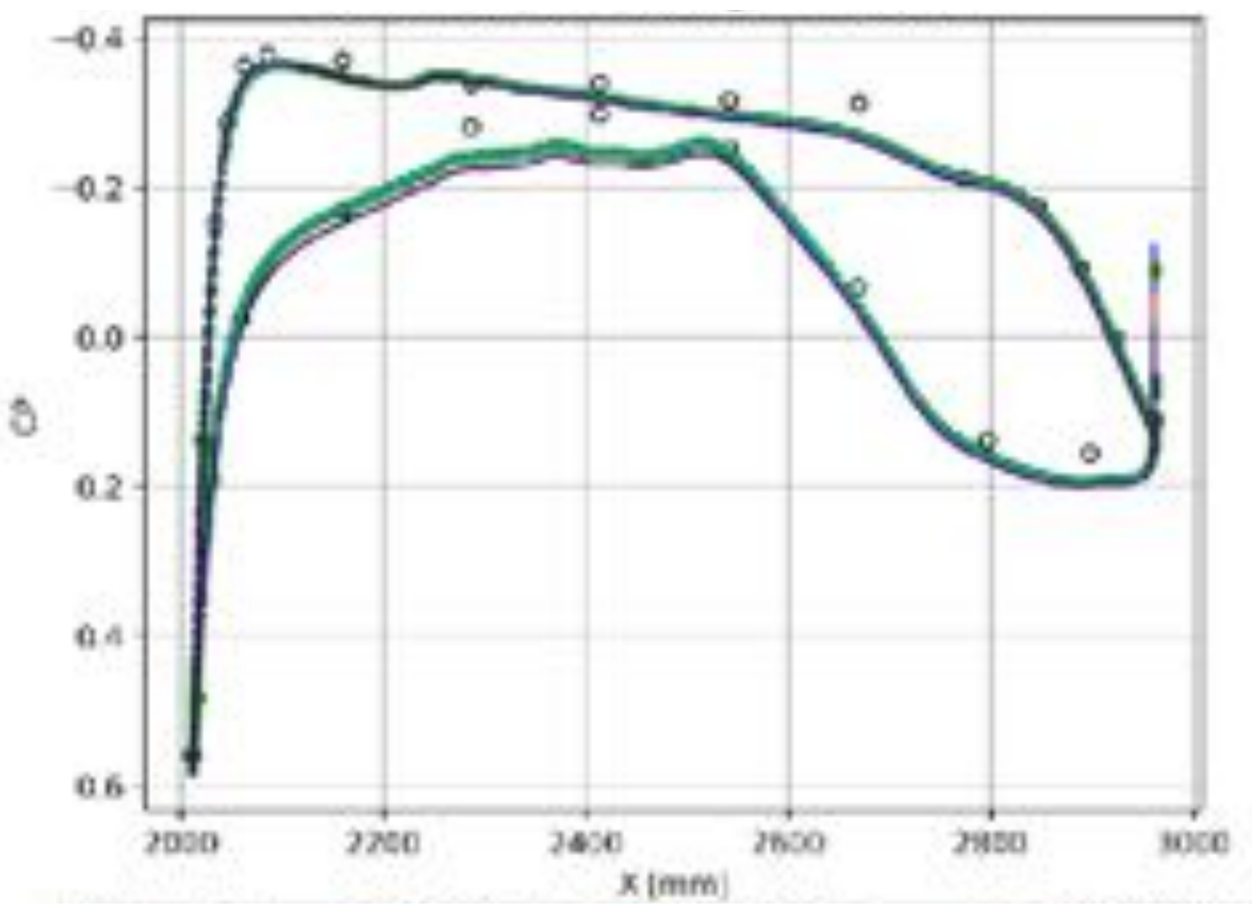
Wing Pressures, AOA = -2.5 deg



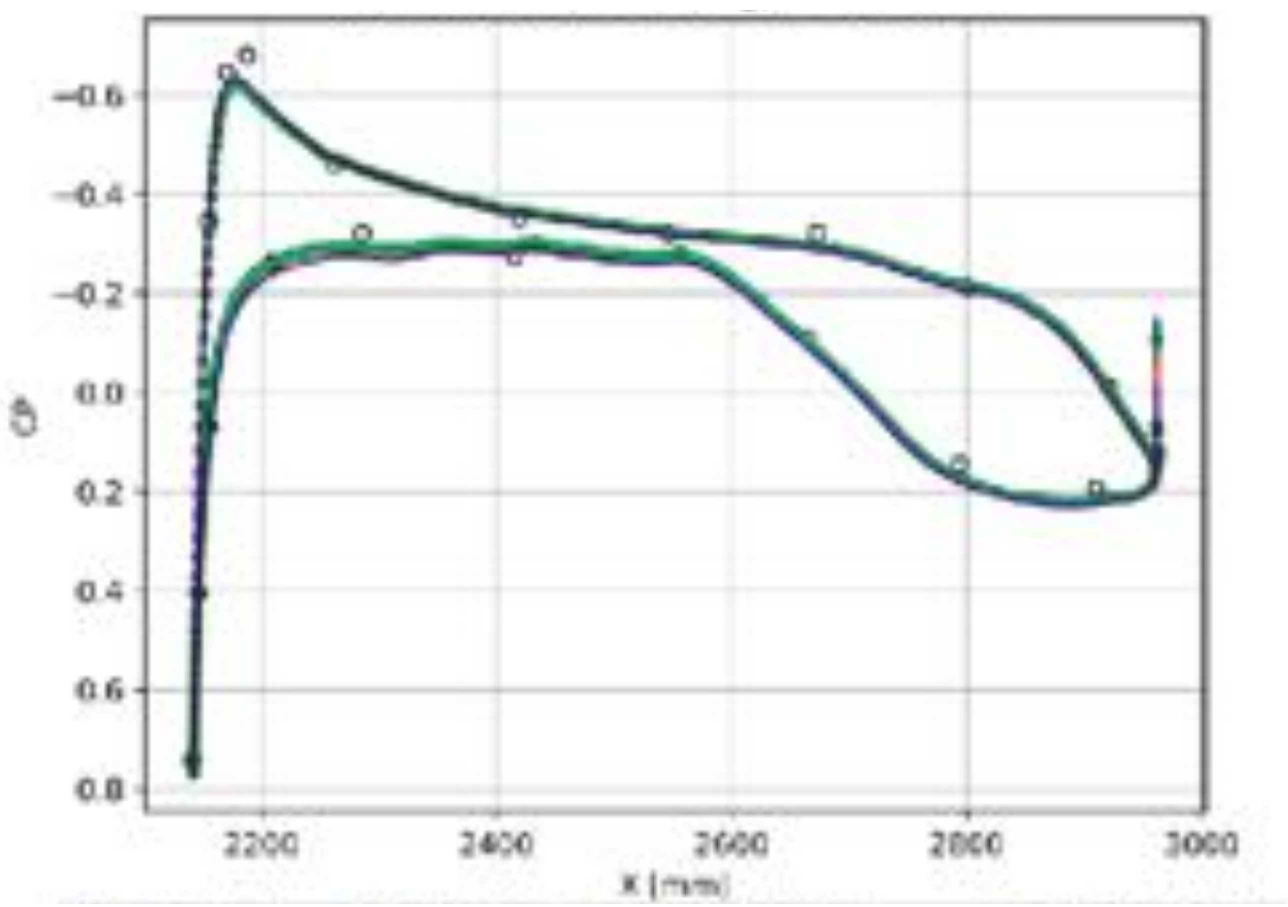
y=254.0 mm



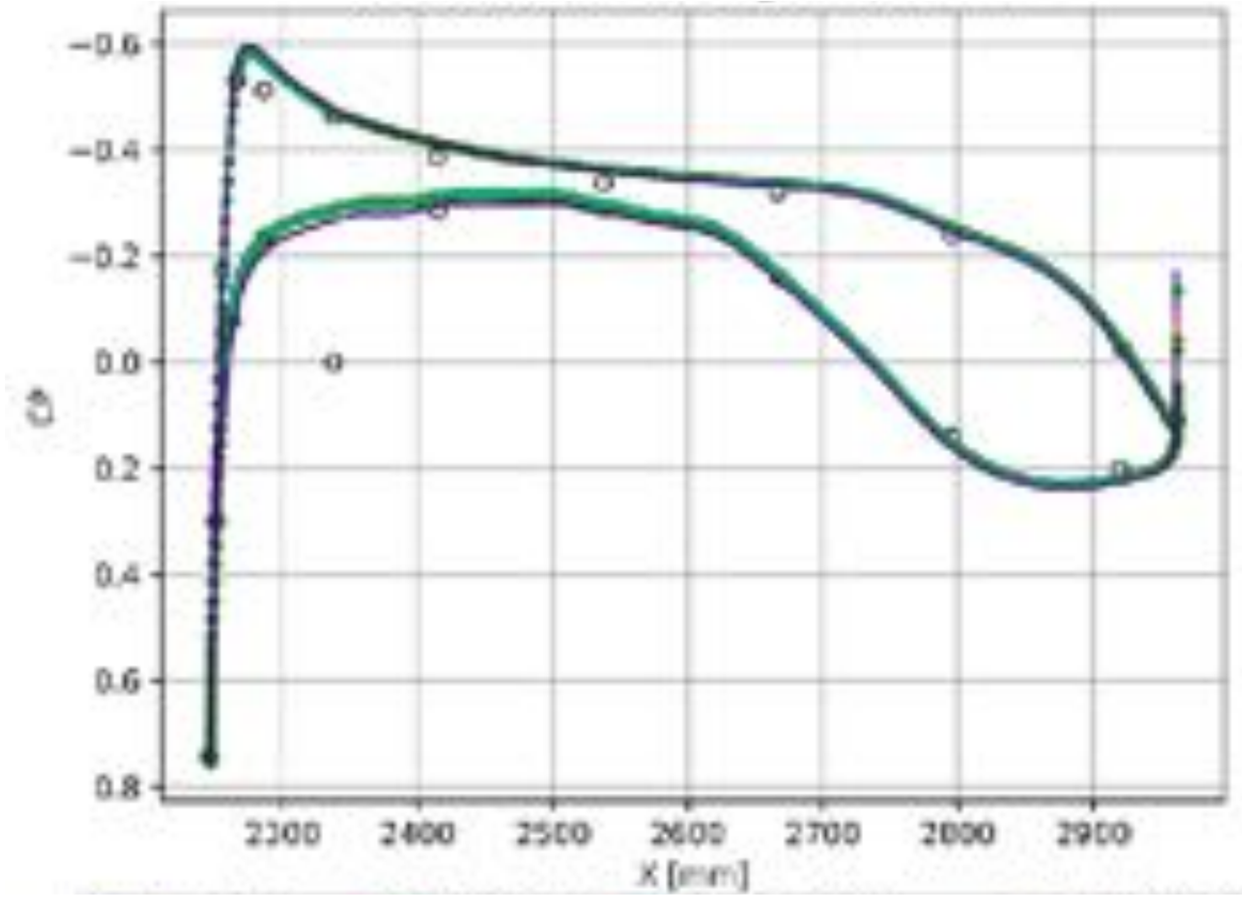
y=290.83 mm



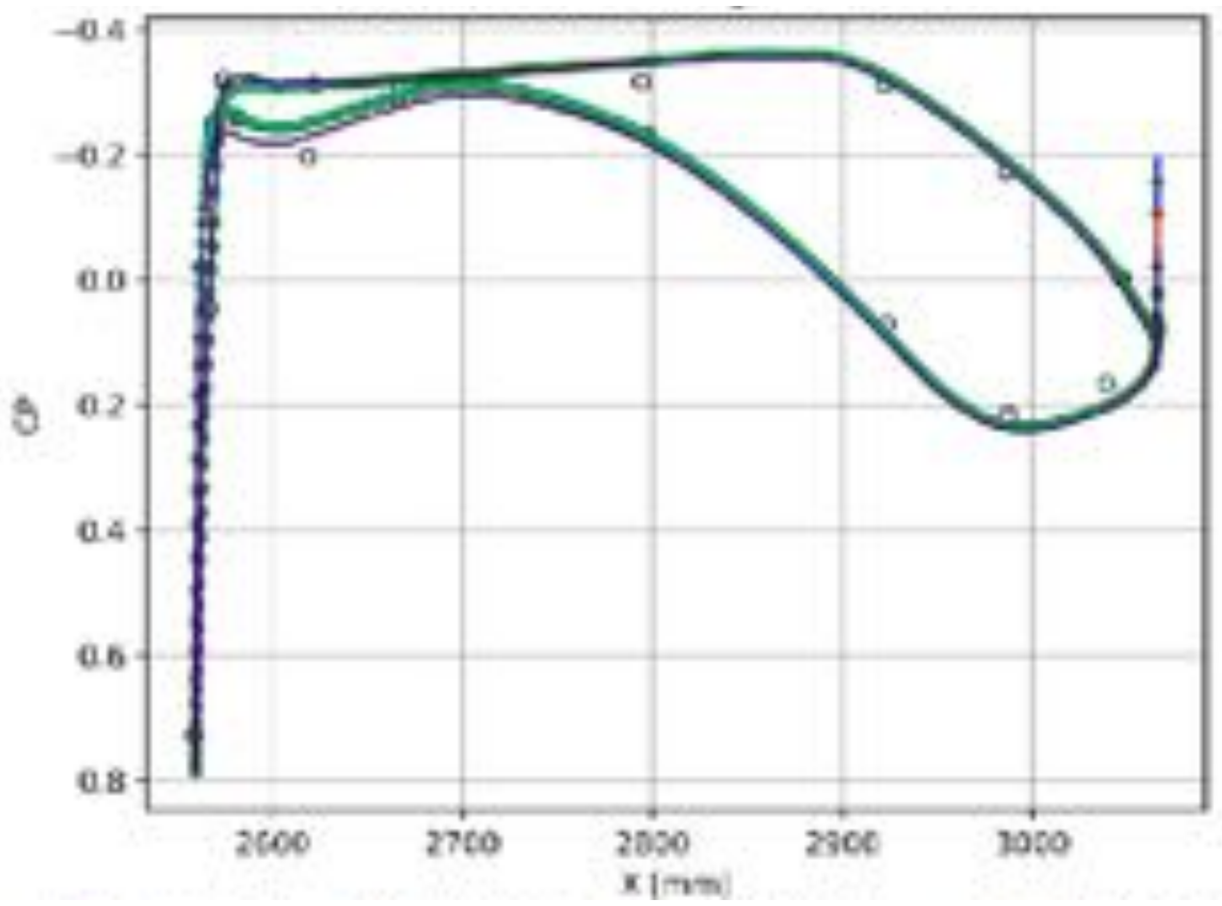
y=482.6 mm



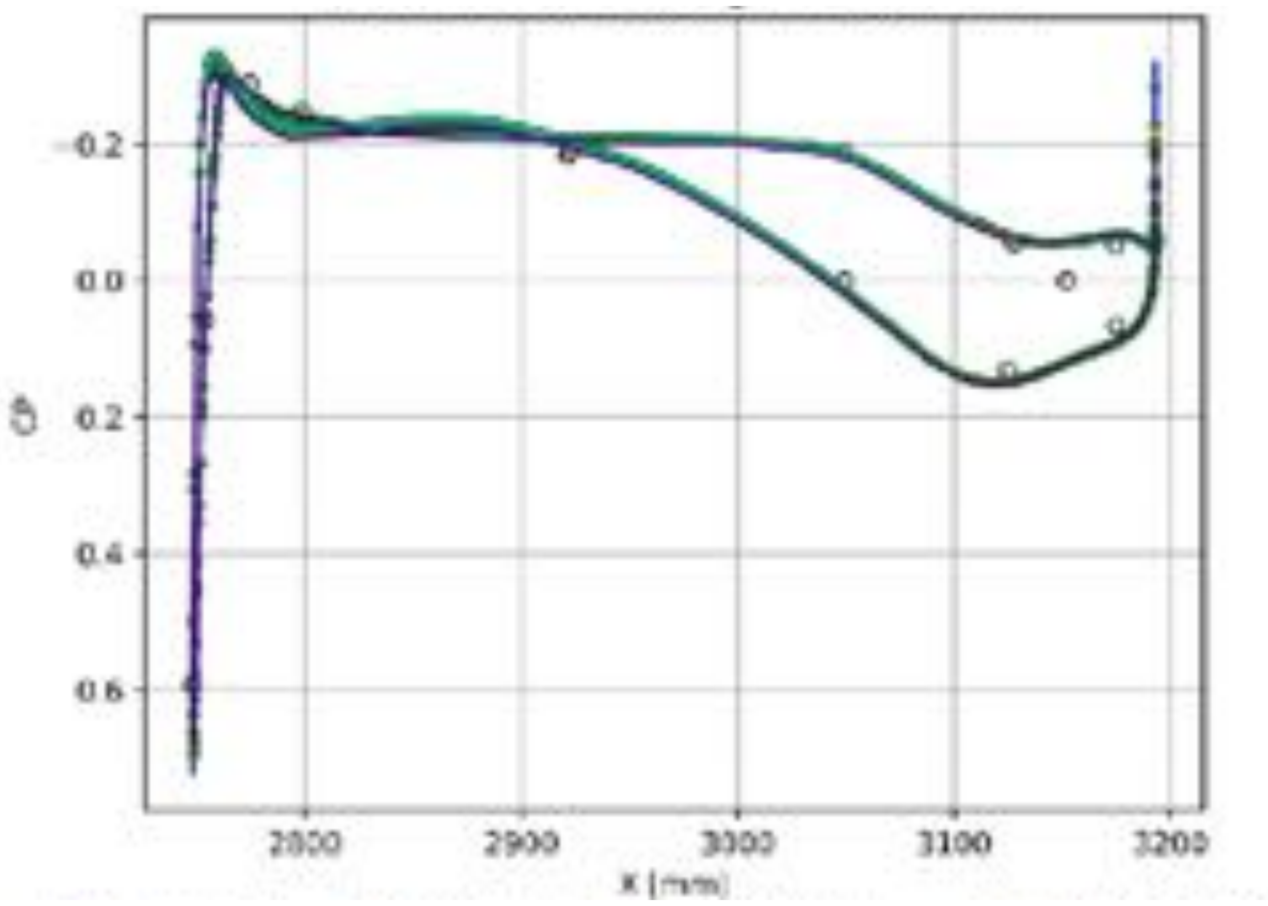
y=685.8 mm



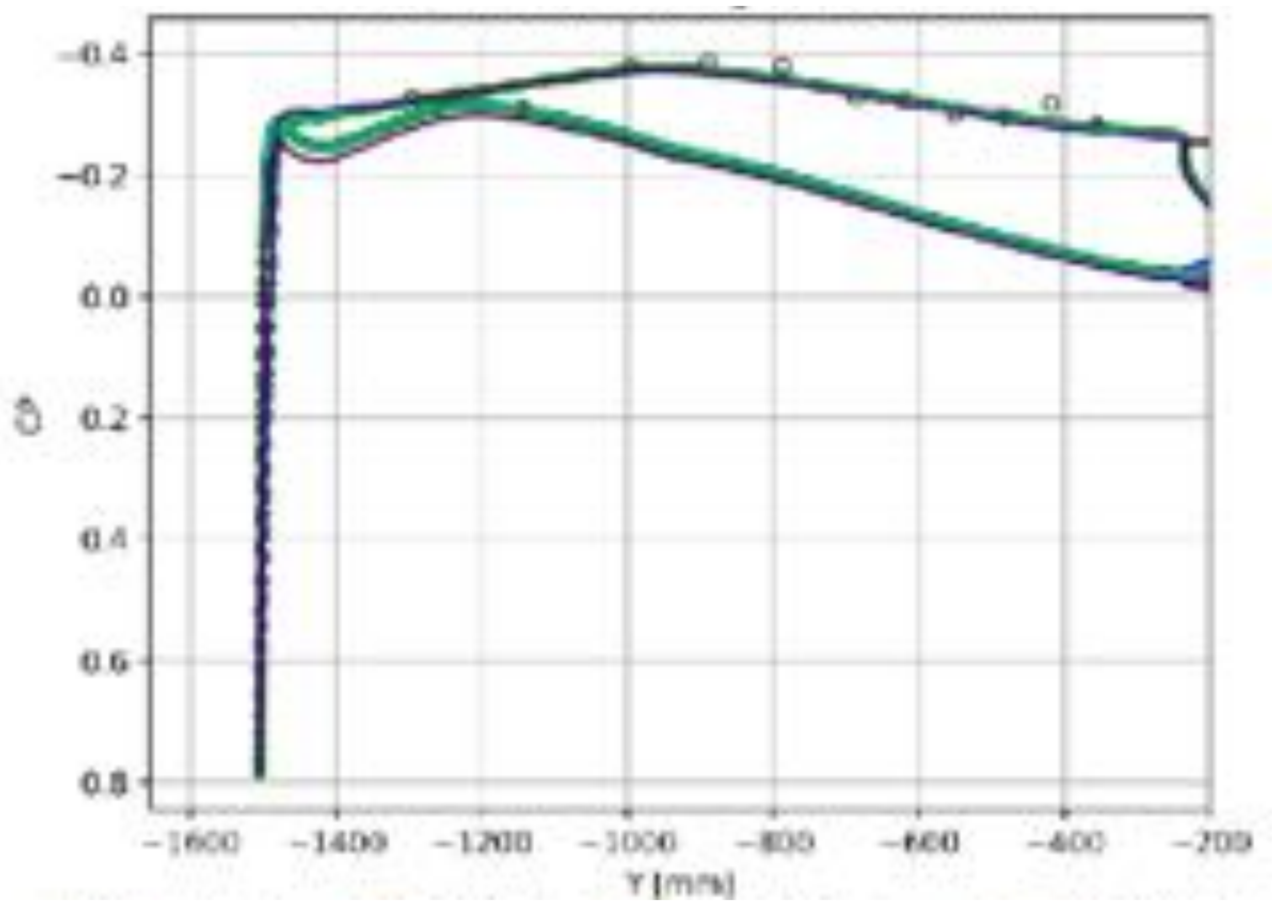
y=1295.4 mm

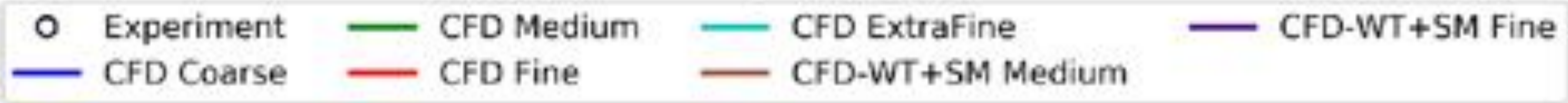


y=1663.7 mm



x=2667 mm

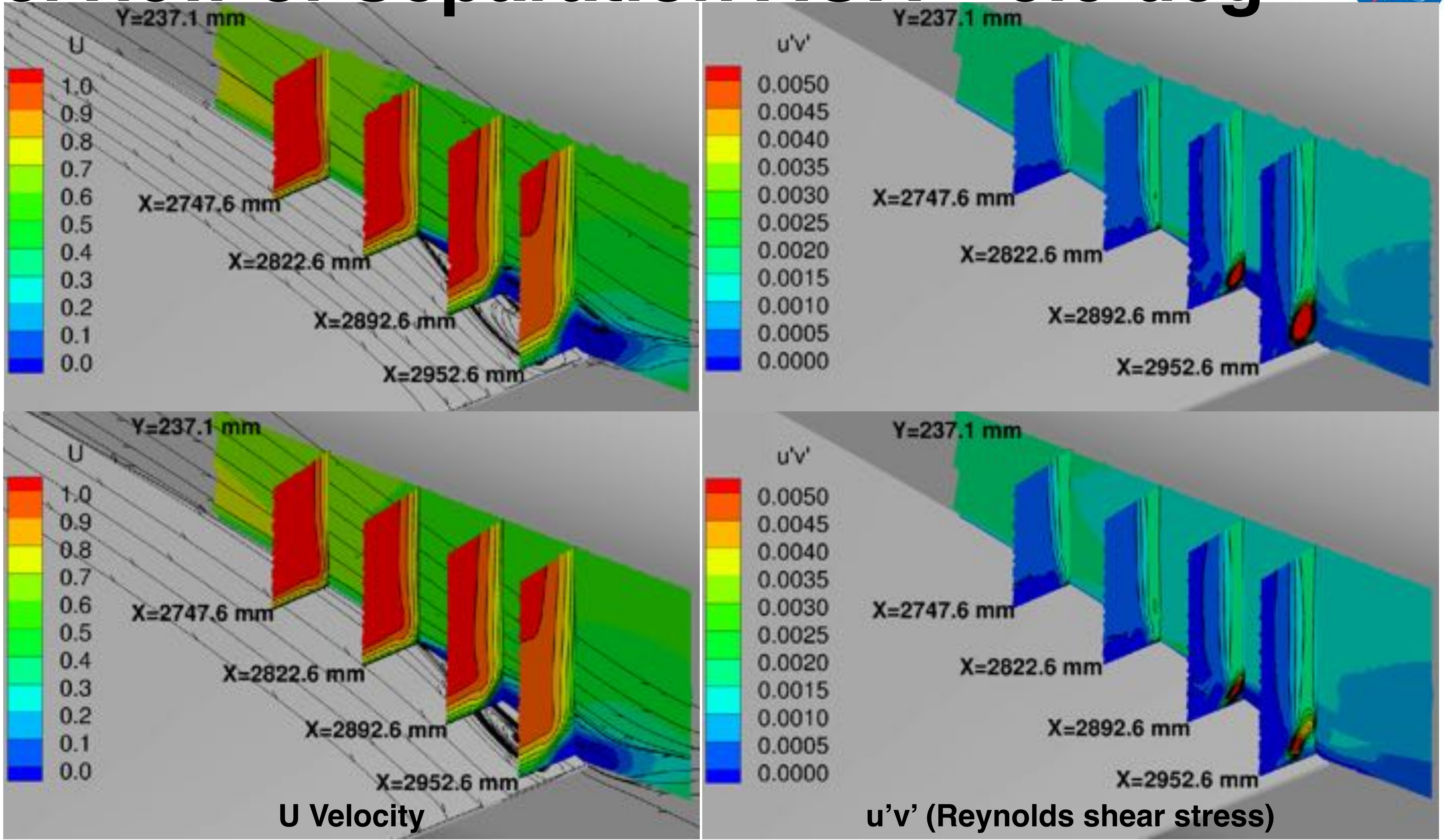




Overview of Separation AOA = 5.0 deg

Medium Grid (Air)

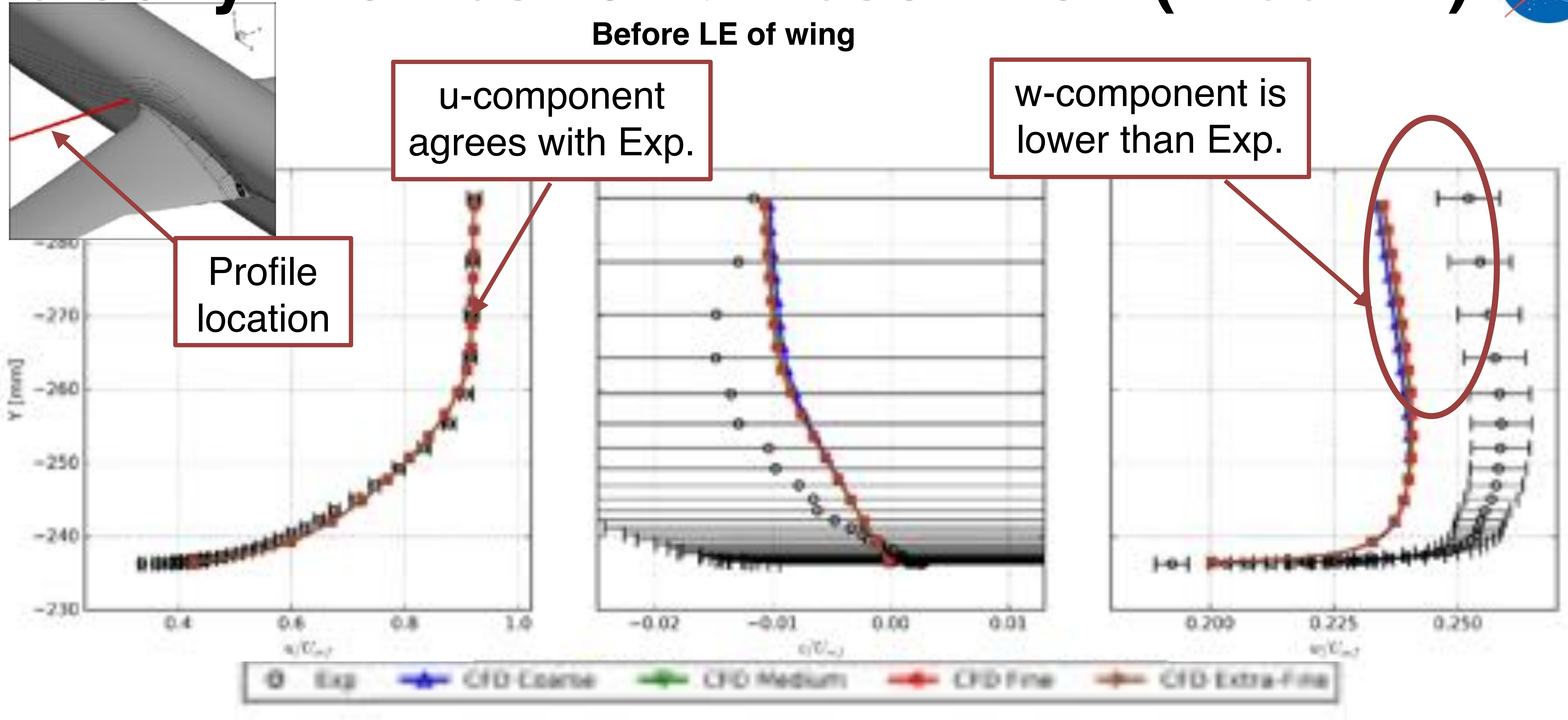
Fine Grid (Air)



U Velocity

u’v’ (Reynolds shear stress)

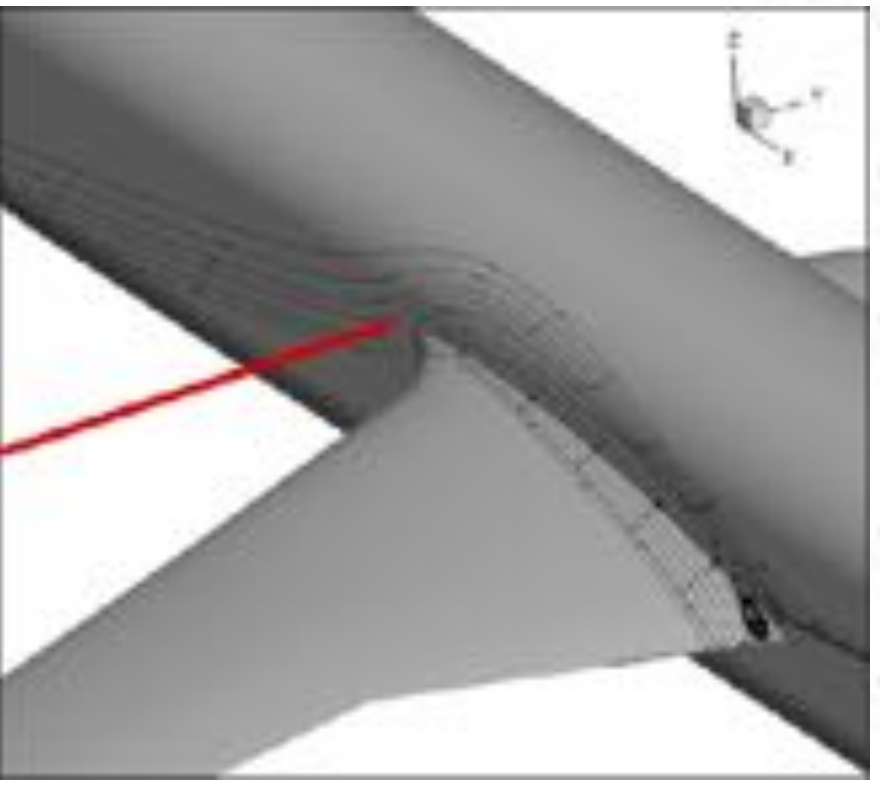
Velocity Profiles: Grid Resolution (Free Air)

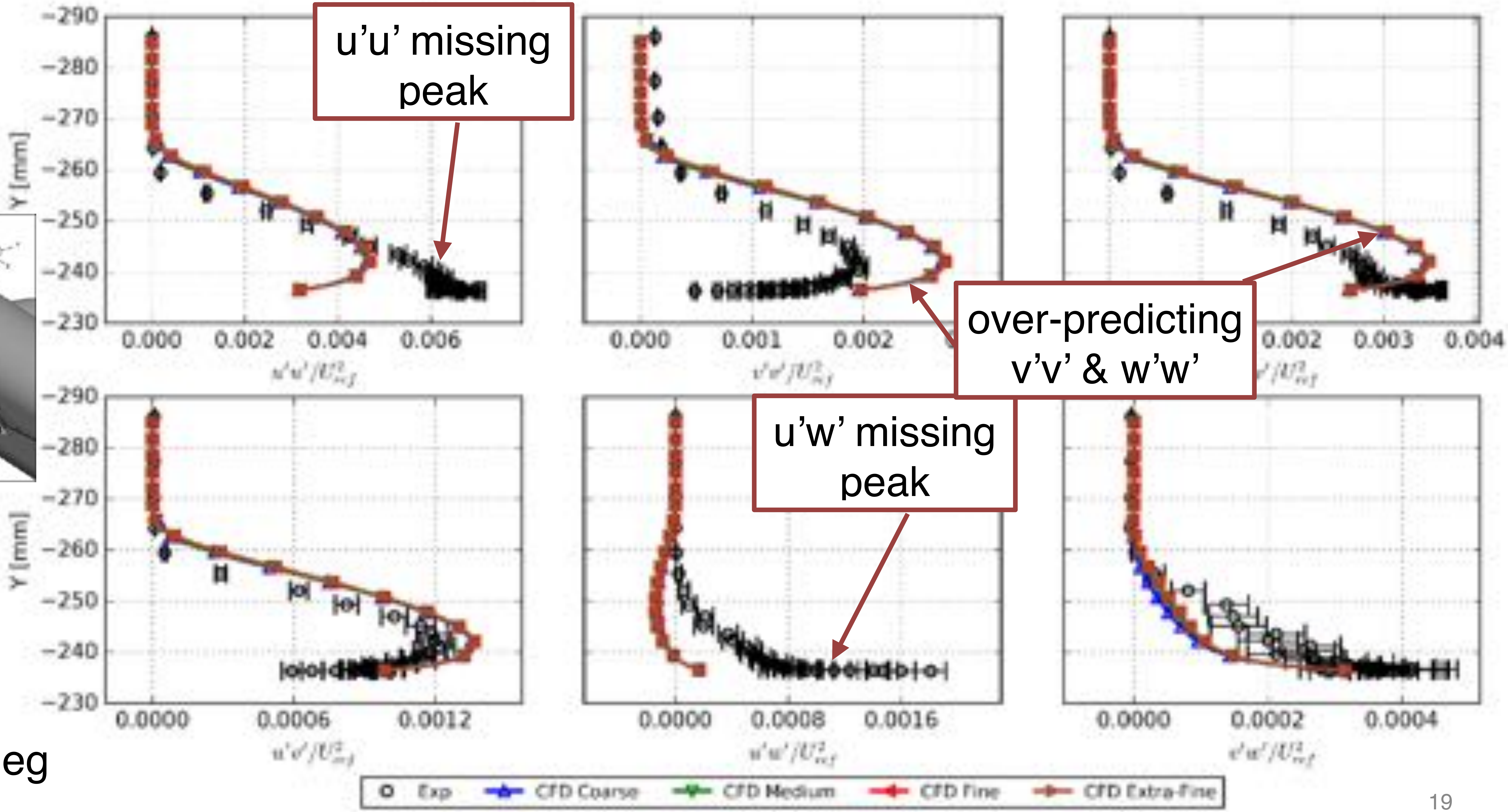


AOA = 5 deg

Reynolds Stress Profiles: Grid Resolution (Free Air)

Before LE of wing

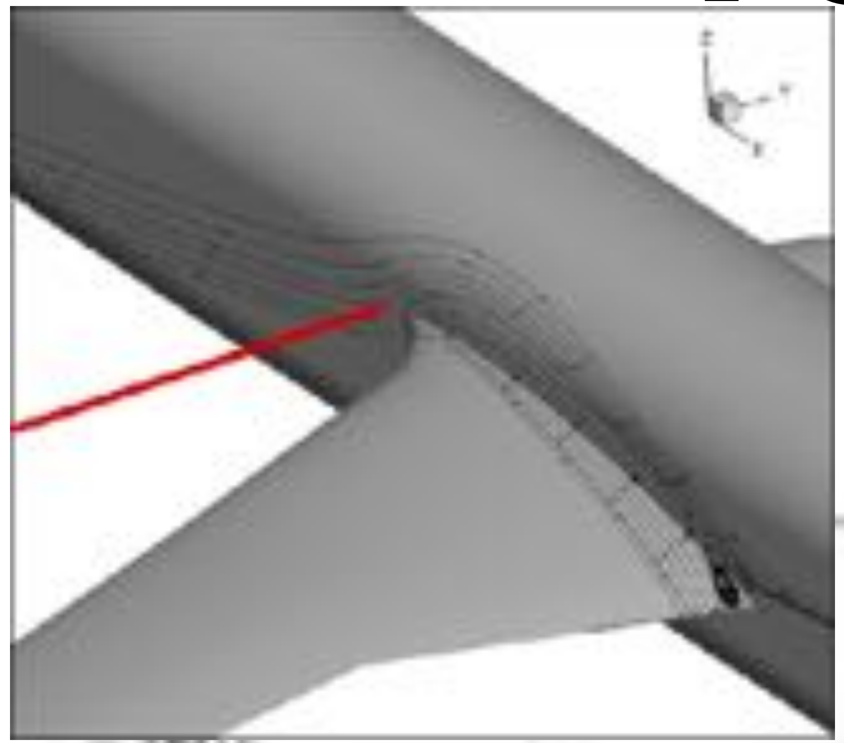


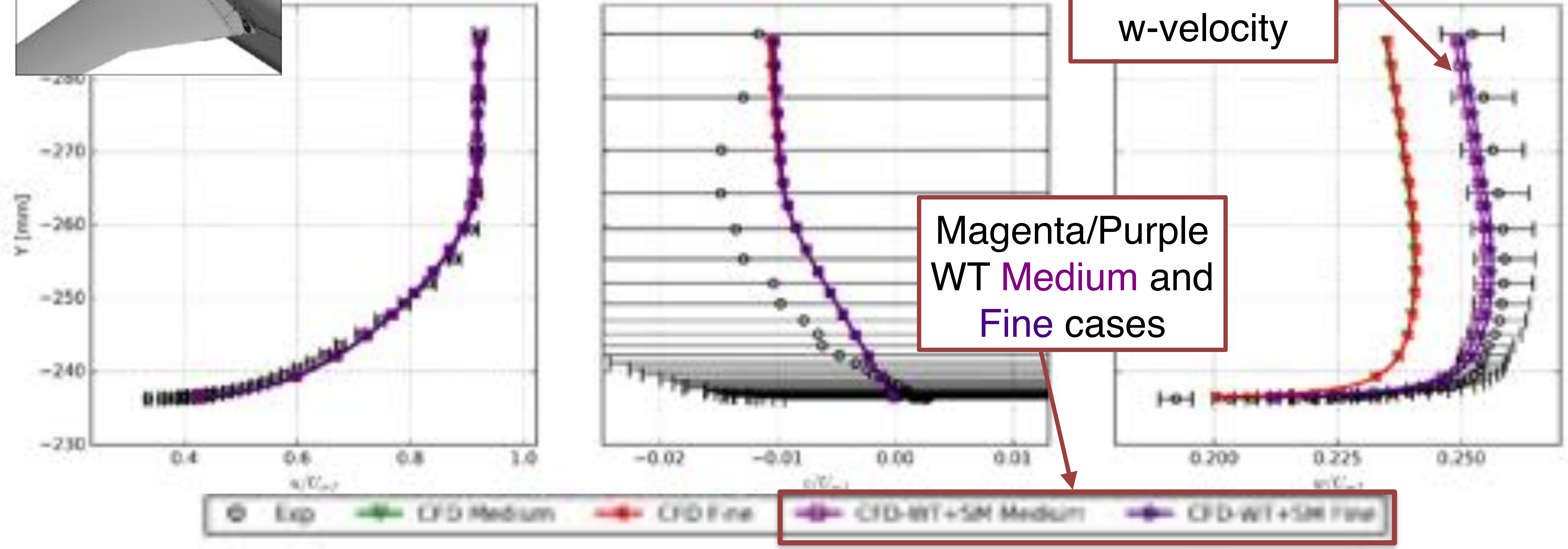


AOA = 5 deg

Velocity Profiles: Wall Effect

Before LE of wing





Adding WT walls recover w-velocity

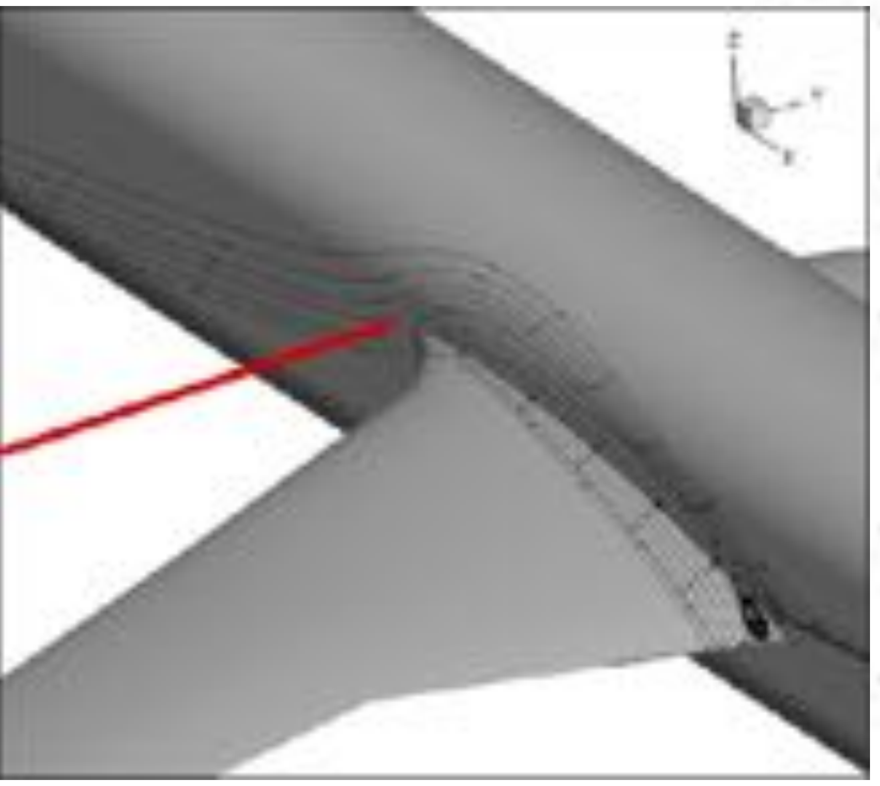
Magenta/Purple WT Medium and Fine cases

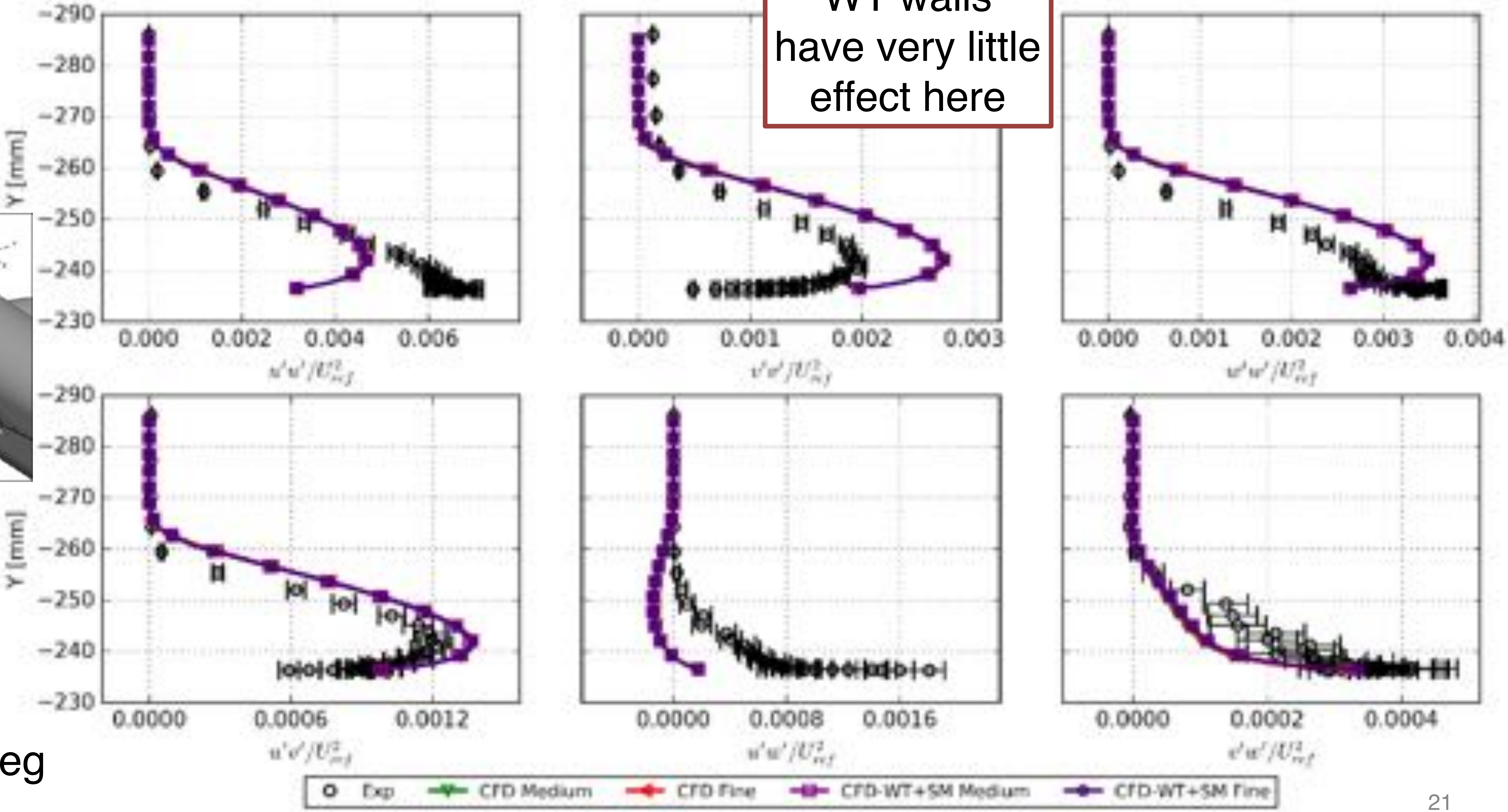
AOA = 5 deg

Reynolds Stress Profiles: Wall Effect

Before LE of wing

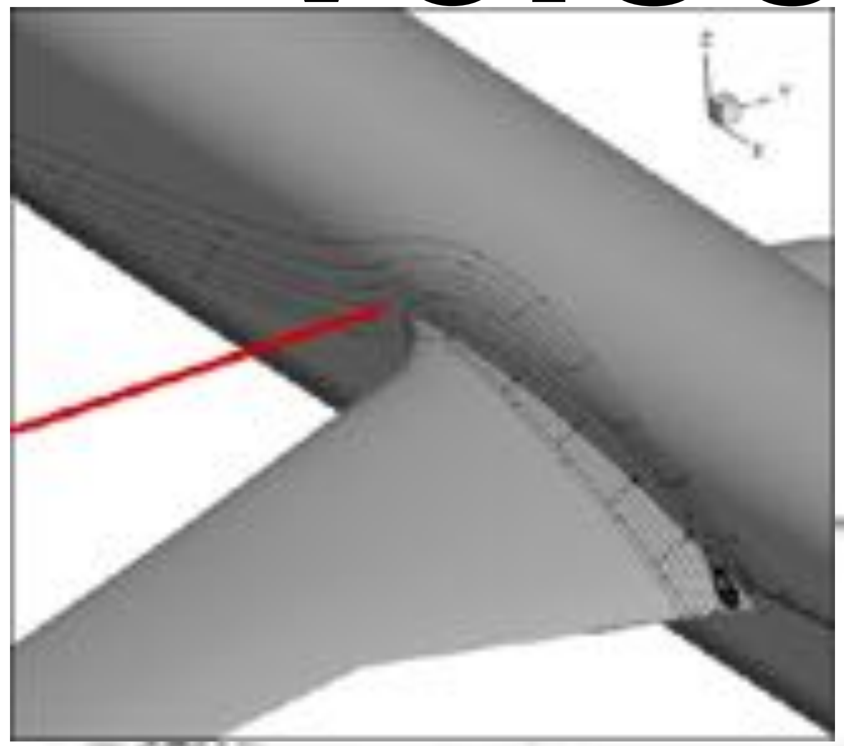
WT walls have very little effect here





AOA = 5 deg

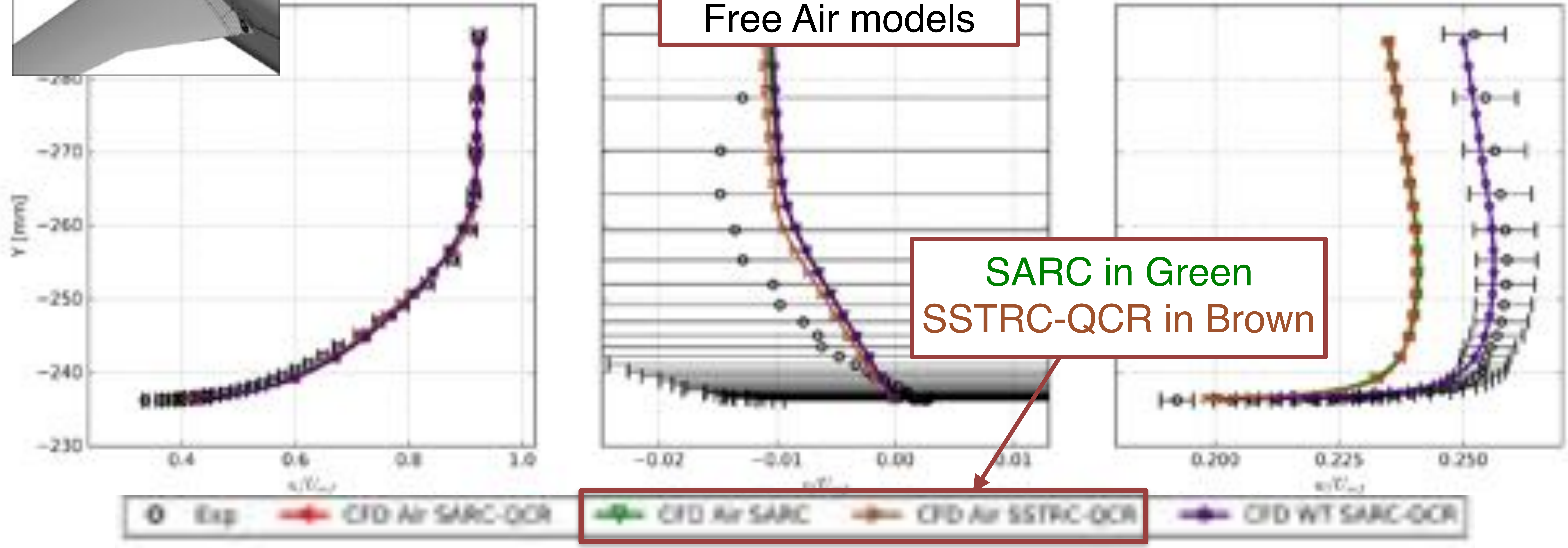
Velocity Profiles: Turbulence Model



Before LE of wing

Profiles look similar between all Turb. Free Air models

SARC in Green
SSTRC-QCR in Brown



AOA = 5 deg

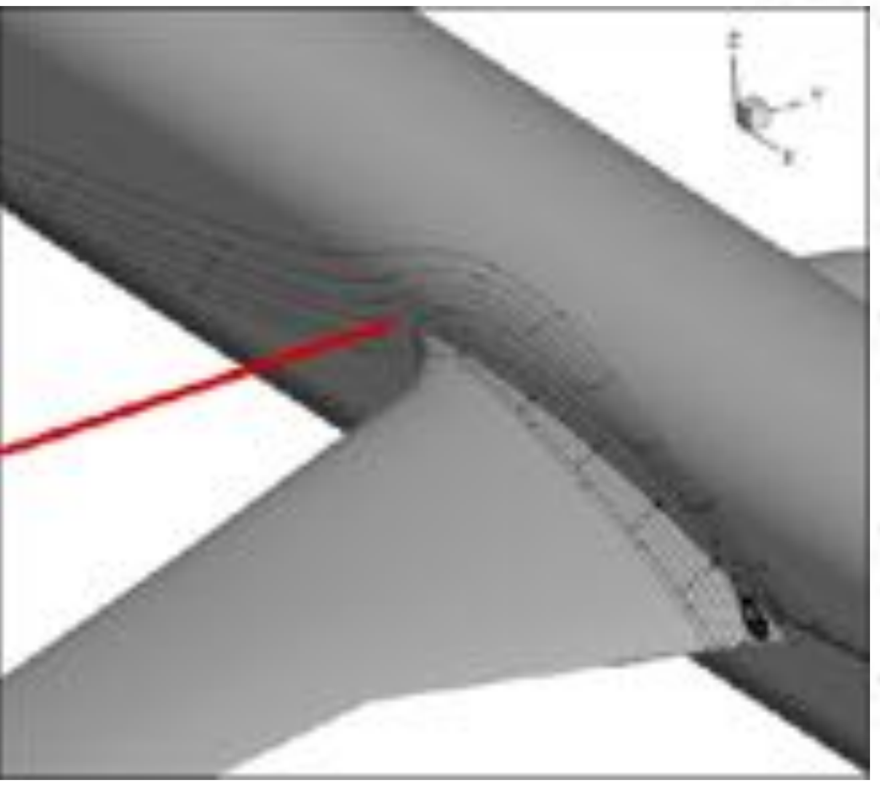
Reynolds Stress Profiles: Turbulence Model

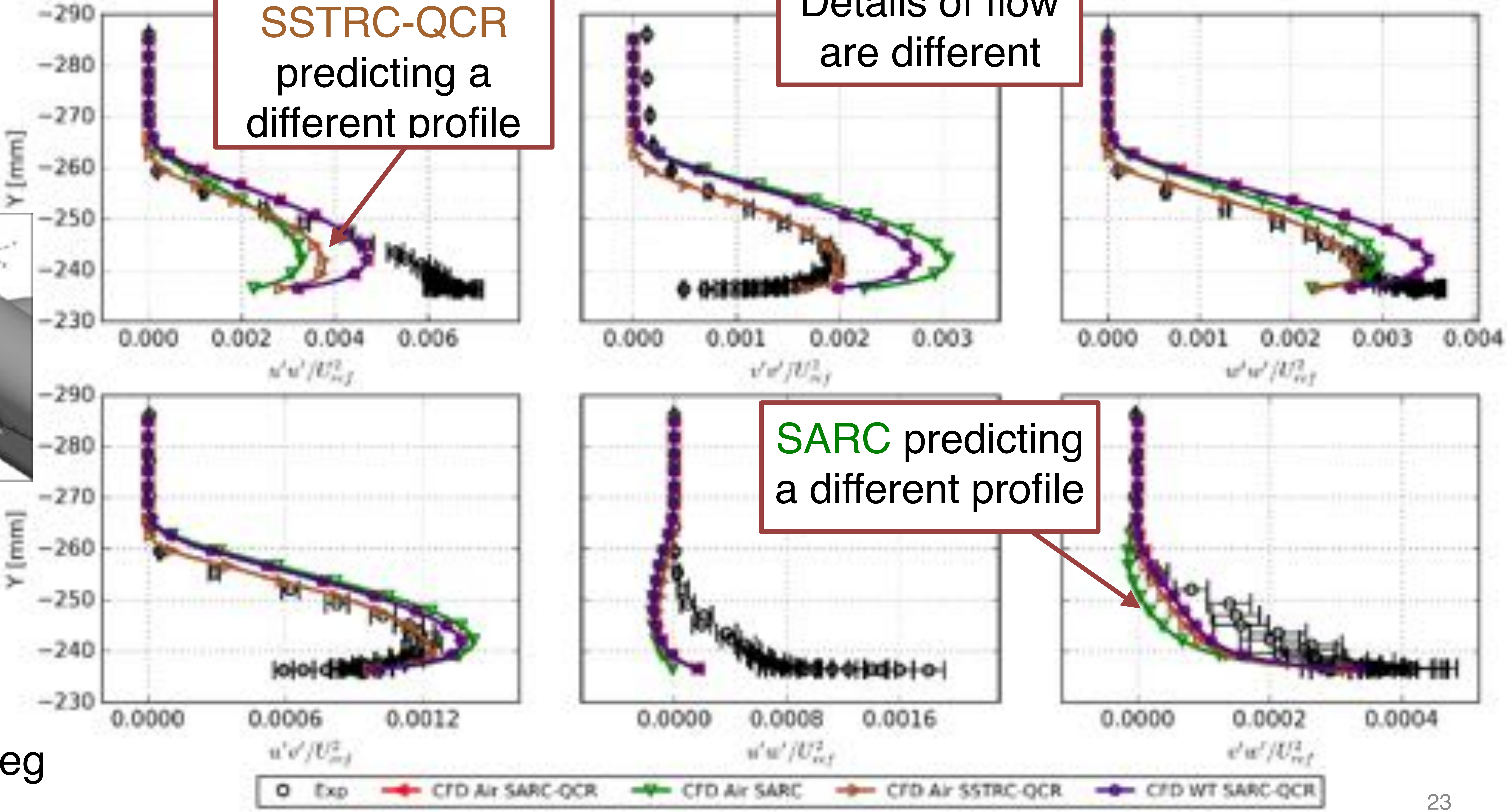
Before LE of wing

SSTRC-QCR predicting a different profile

Details of flow are different

SARC predicting a different profile

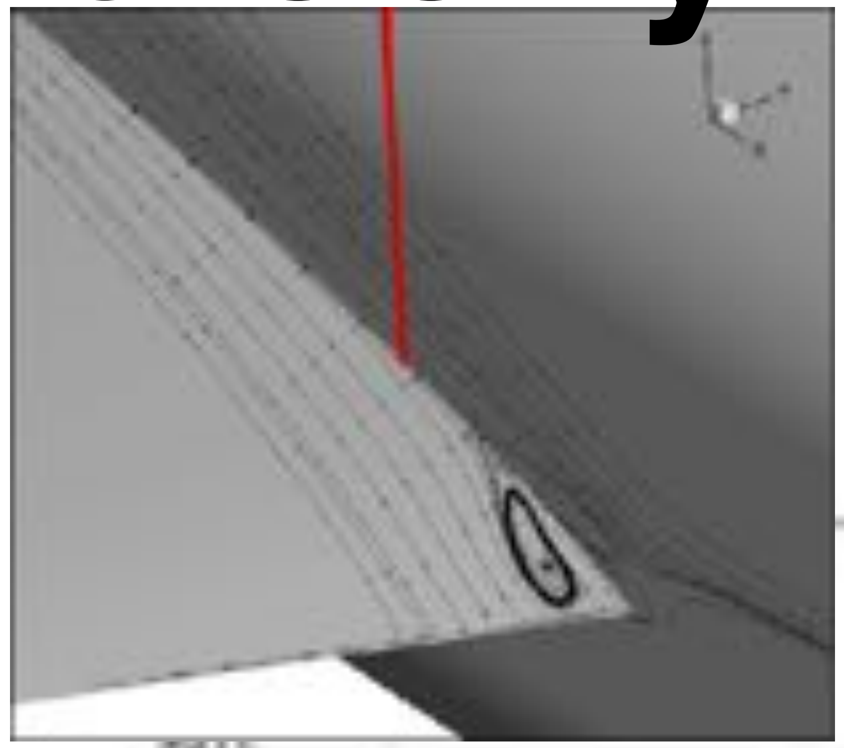




AOA = 5 deg

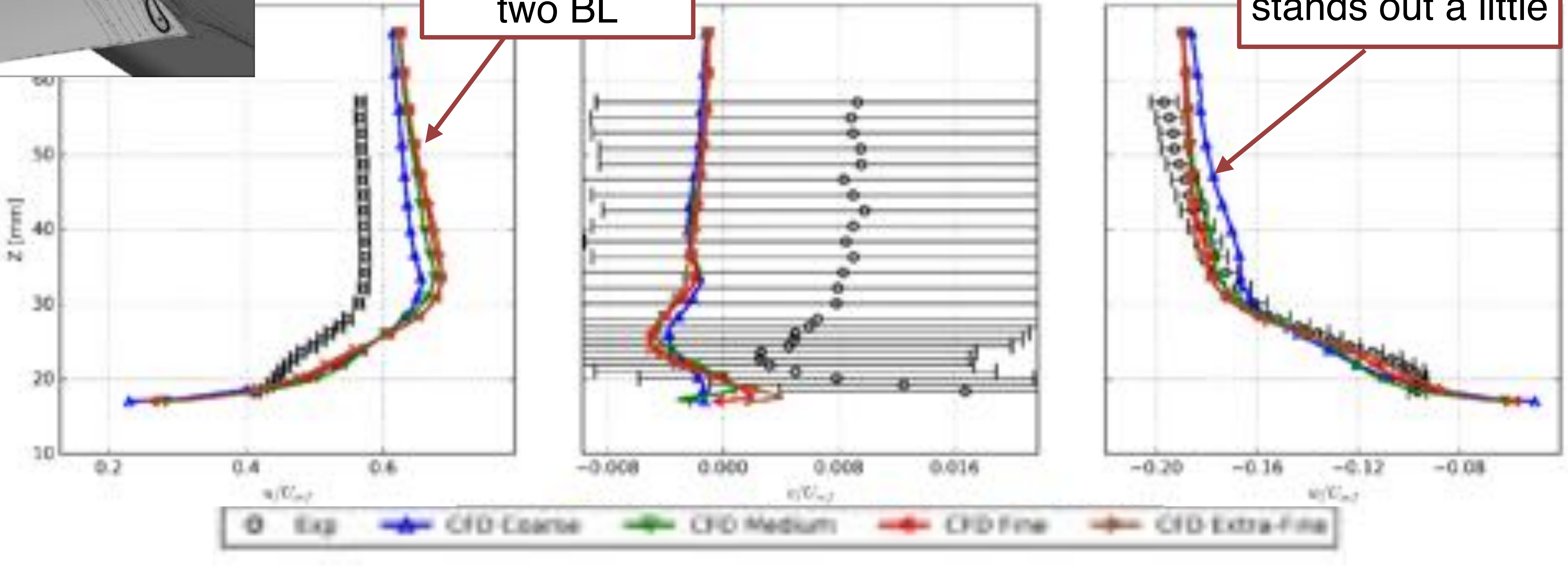
Velocity Profiles: Grid Resolution (Free Air)

Upstream of Separation, 1 mm from fuselage



Shift may be caused by the two BL

Coarse grid stands out a little

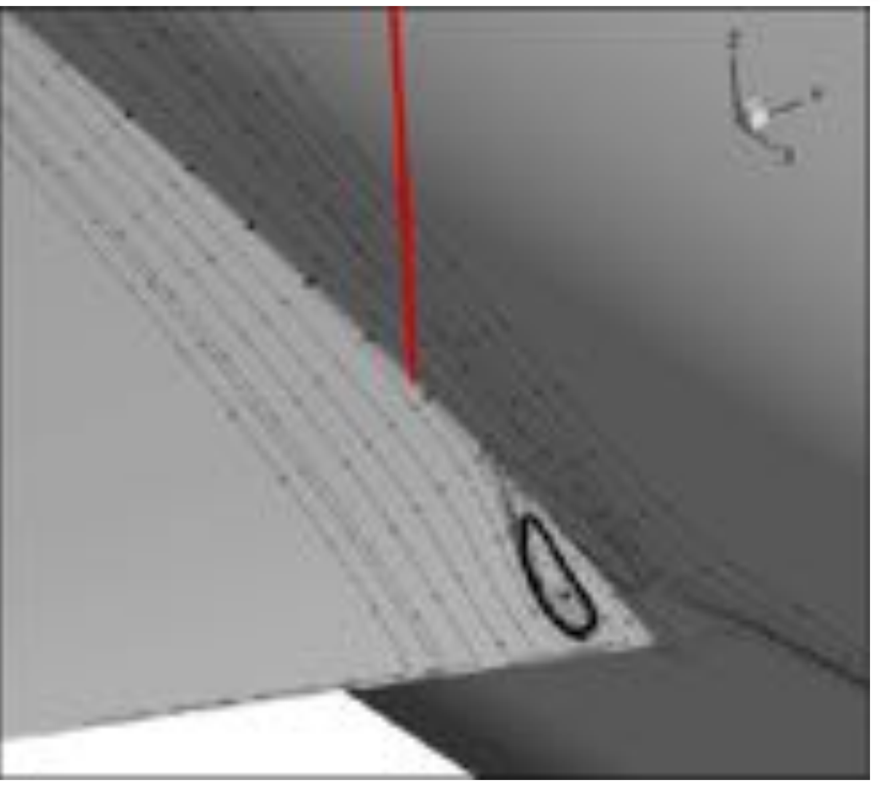


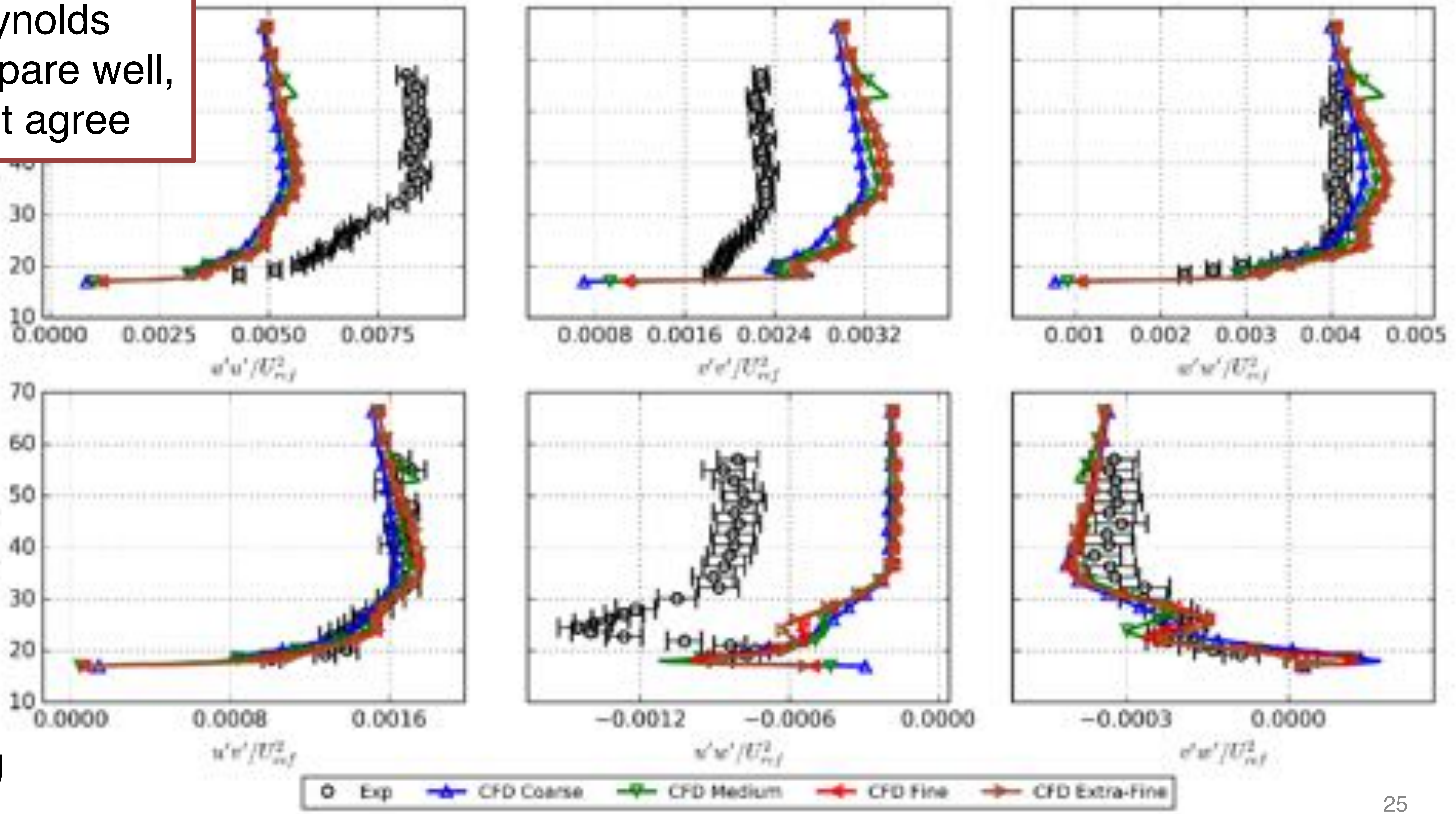
AOA = 5 deg

Reynolds Stress Profiles: Grid Resolution (Free Air)

Upstream of Separation, 1 mm from fuselage

Some Reynolds stresses compare well, others don't agree

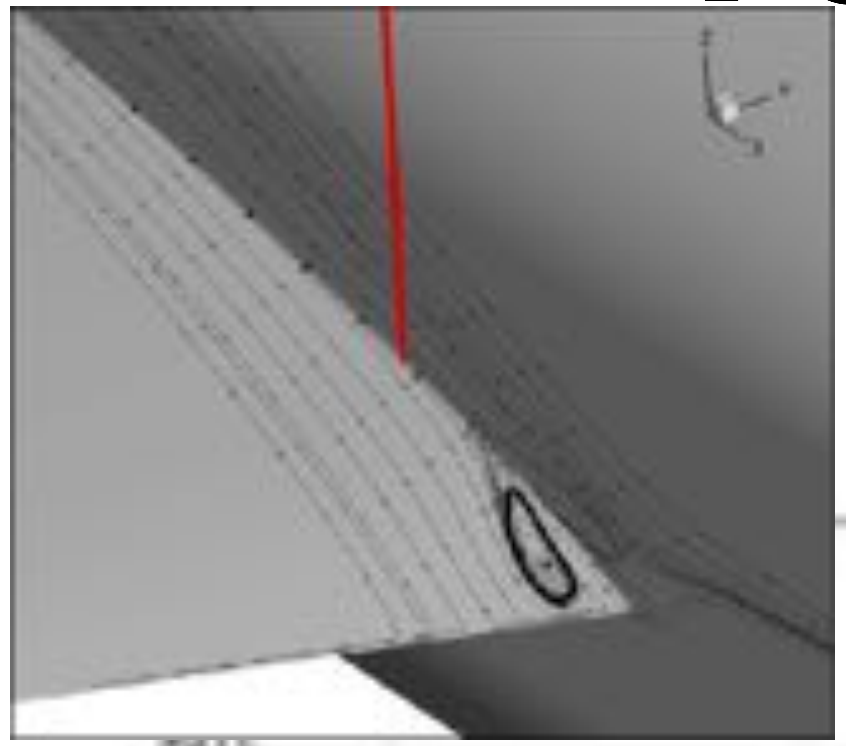




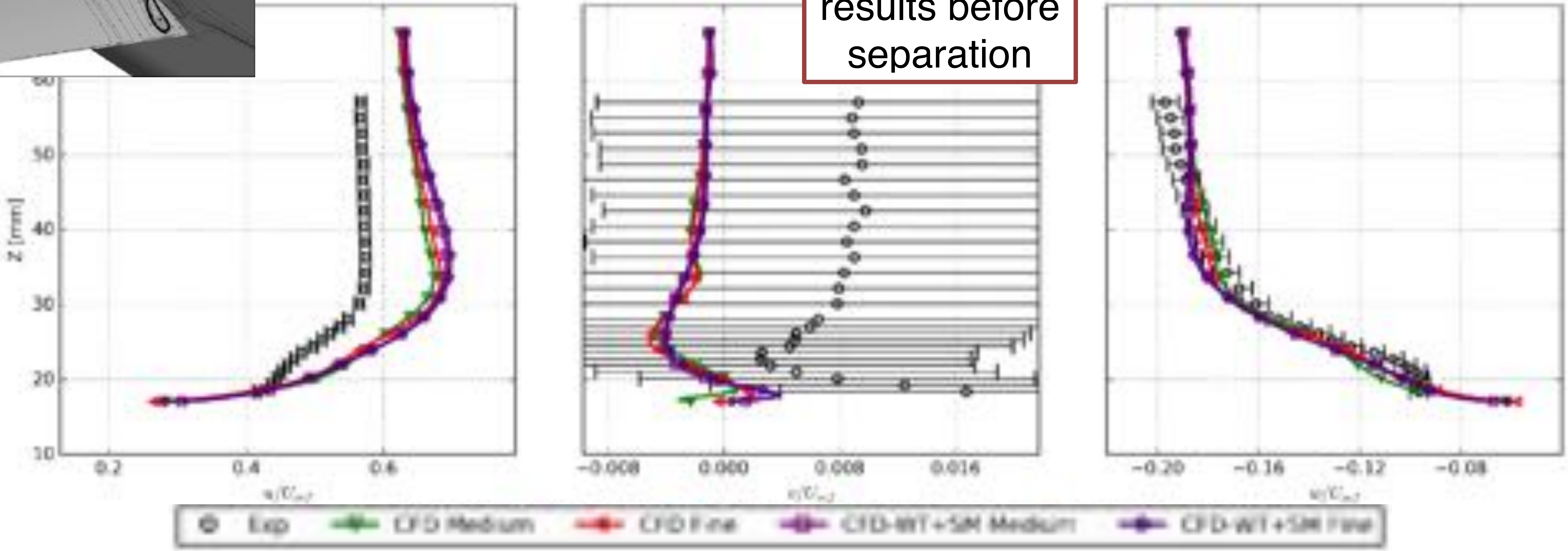
AOA = 5 deg

Velocity Profiles: Wall Effect

Upstream of Separation, 1 mm from fuselage



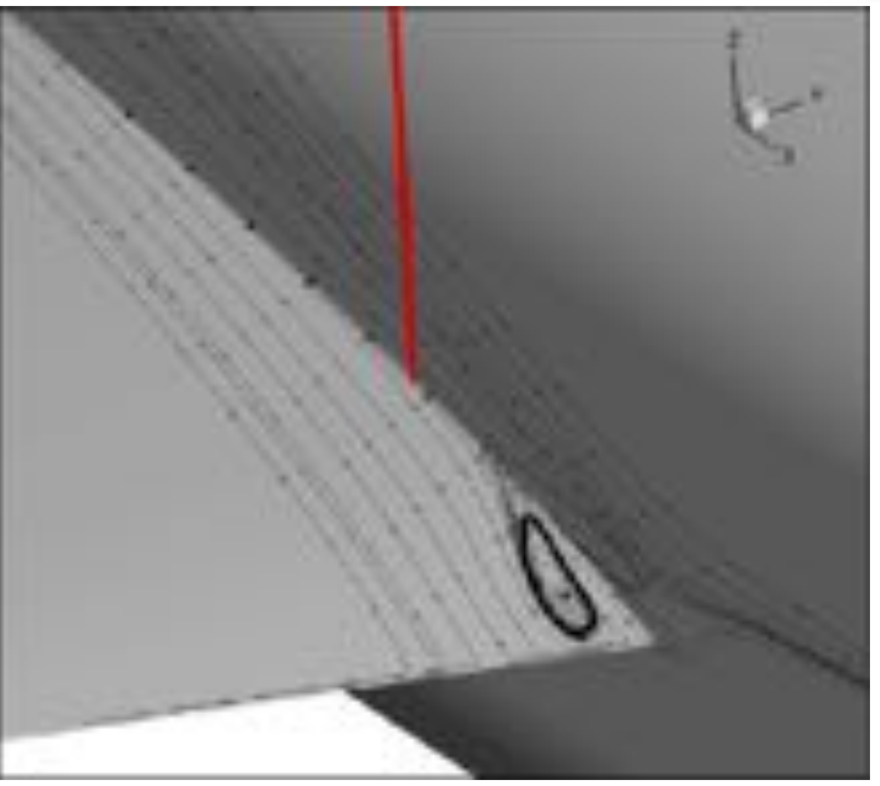
Very similar results before separation

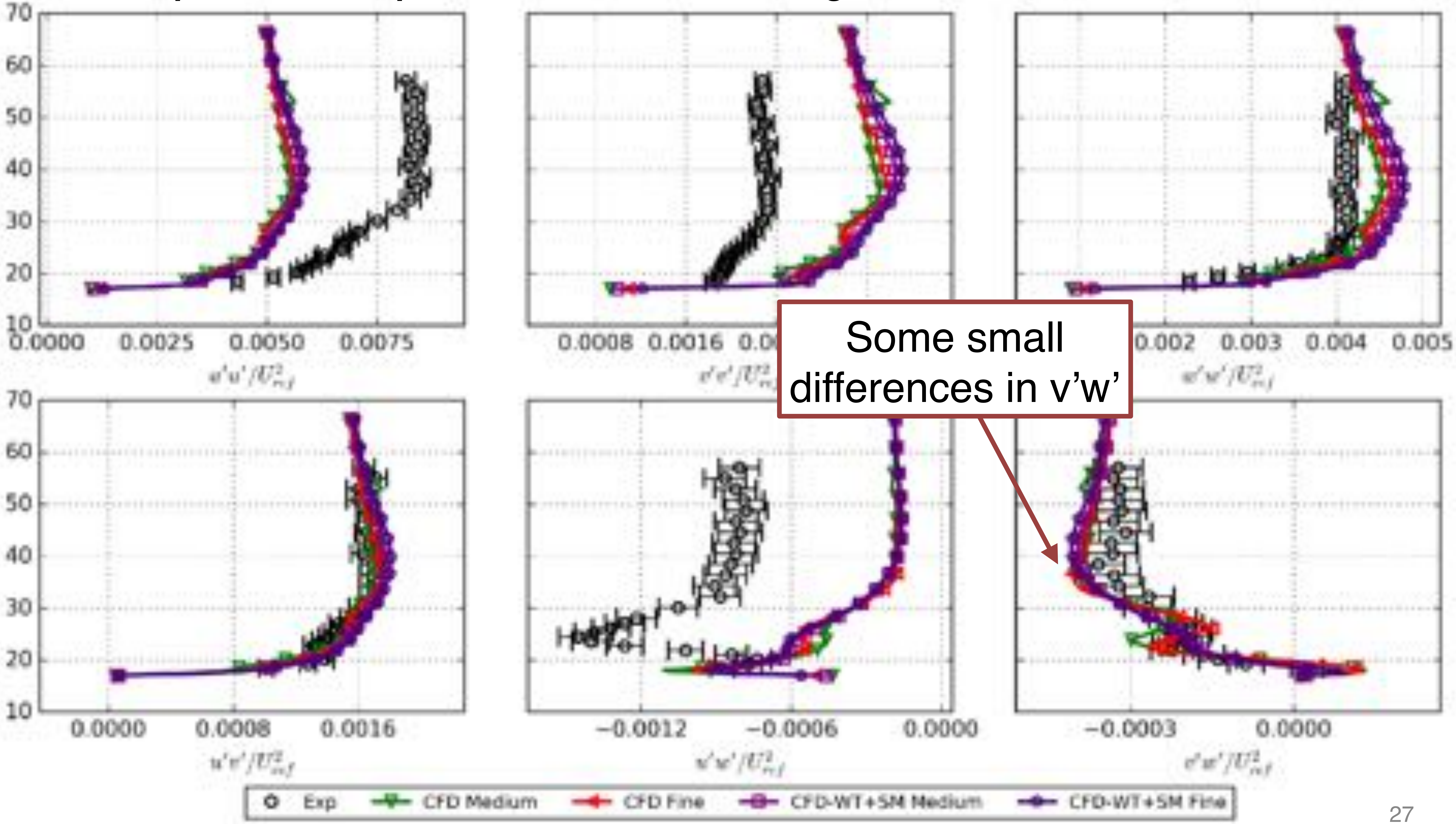


AOA = 5 deg

Reynolds Stress Profiles: Wall Effect

Upstream of Separation, 1 mm from fuselage

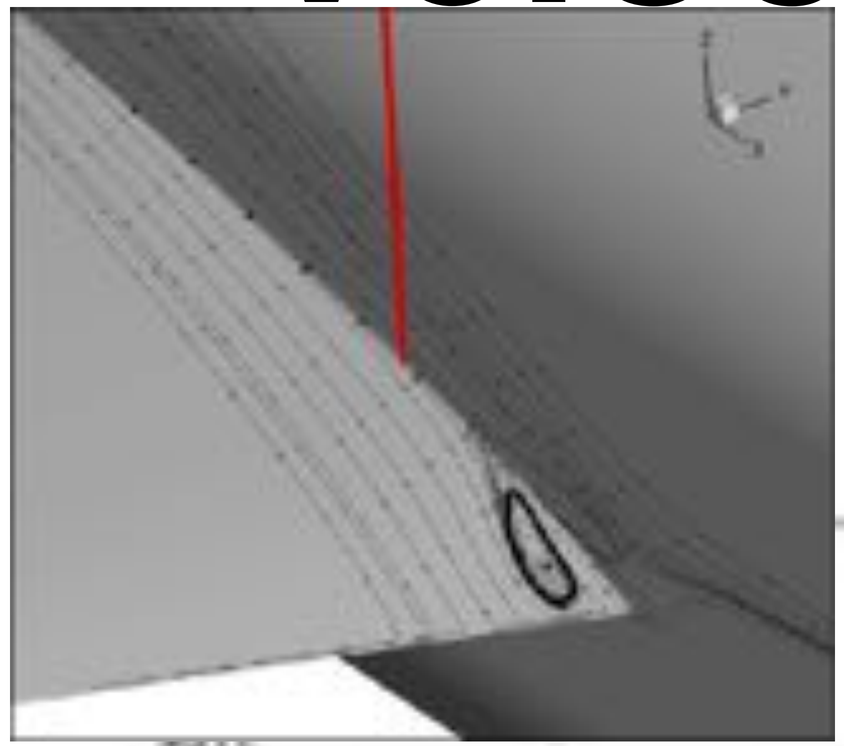




AOA = 5 deg

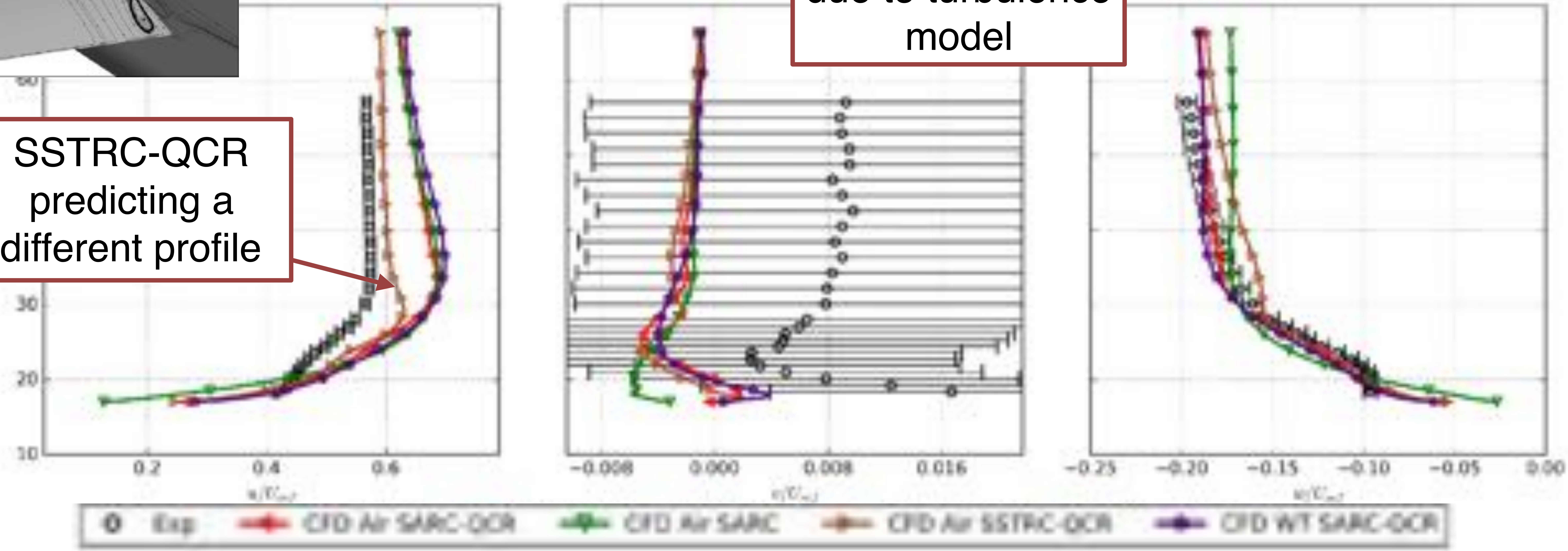
Velocity Profiles: Turbulence Model

Upstream of Separation, 1 mm from fuselage



More variation due to turbulence model

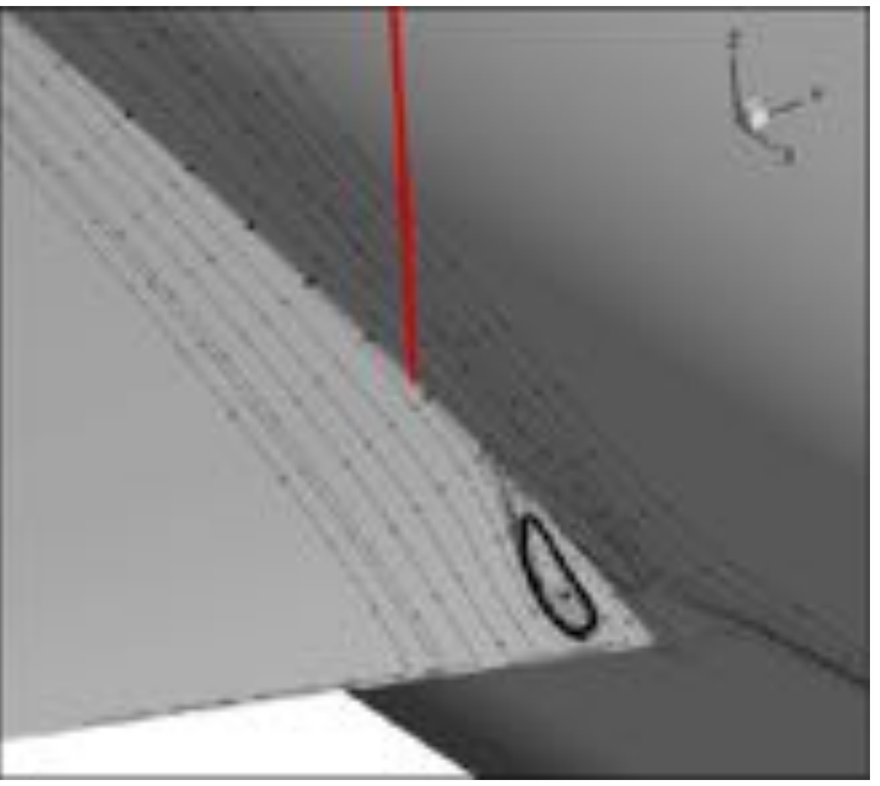
SSTRC-QCR predicting a different profile



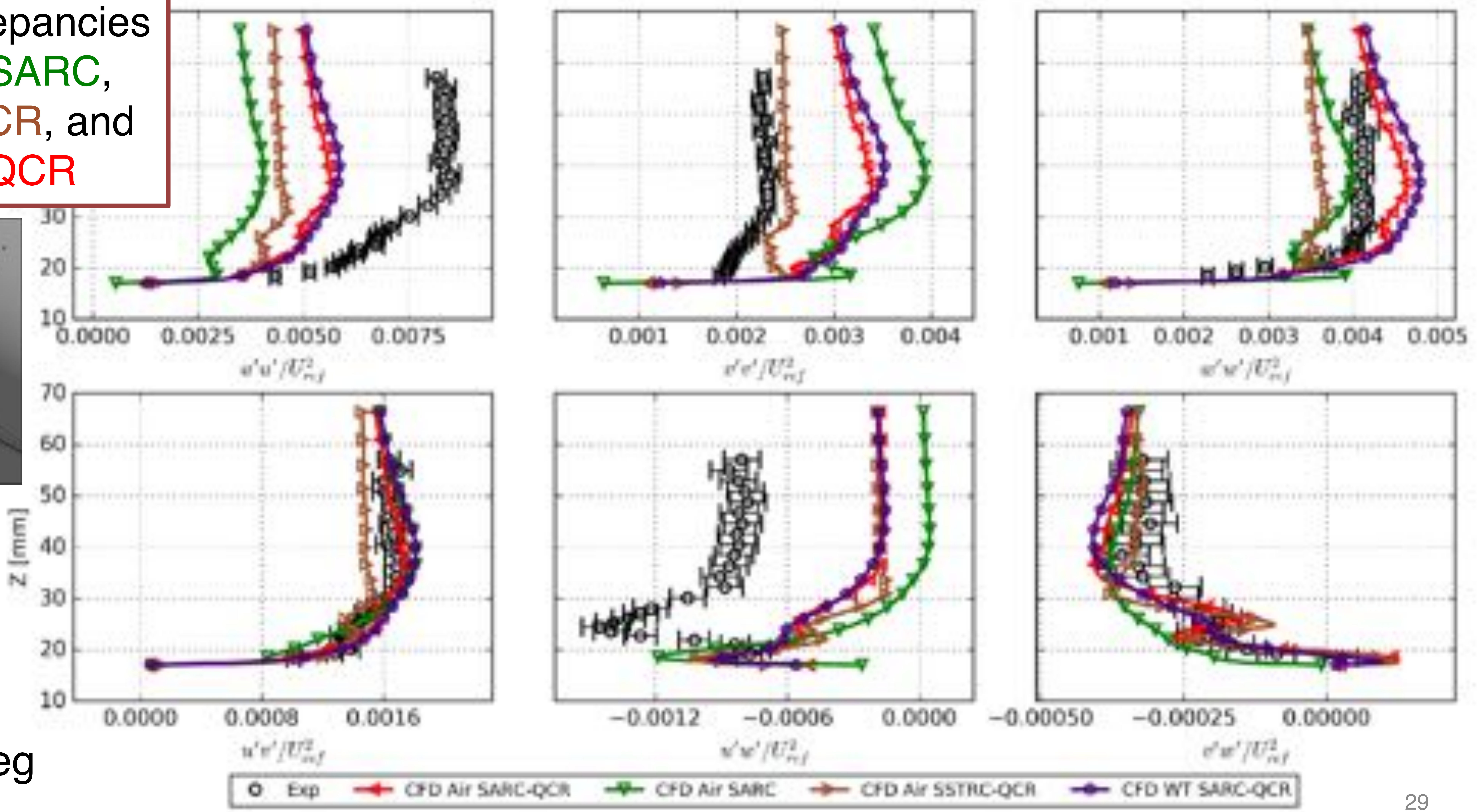
AOA = 5 deg

Reynolds Stress Profiles: Turbulence Model

Large discrepancies between SARC, SSTRC-QCR, and SARC-QCR

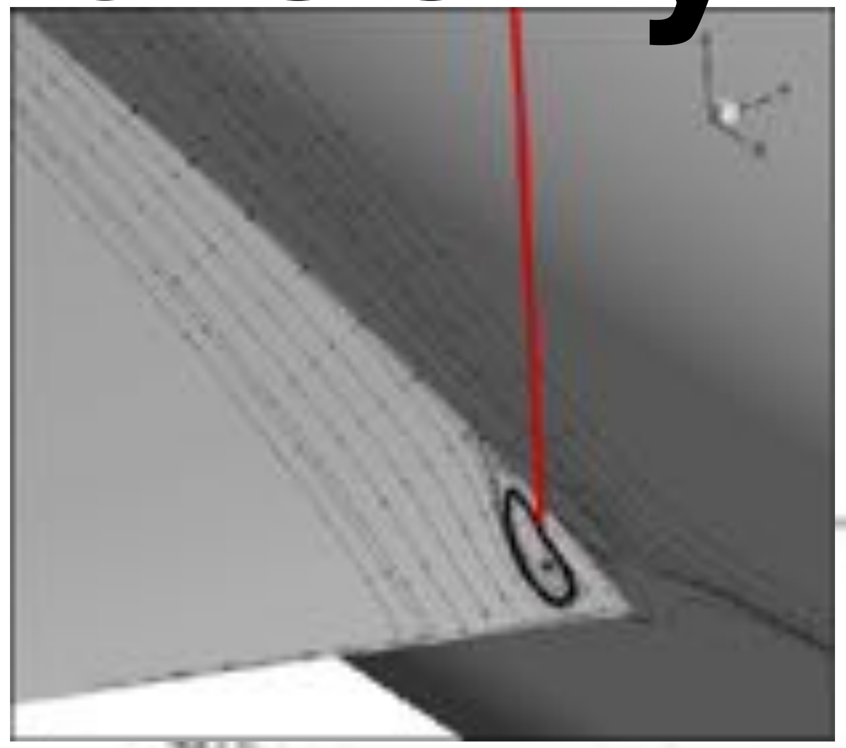


Upstream of Separation, 1 mm from fuselage



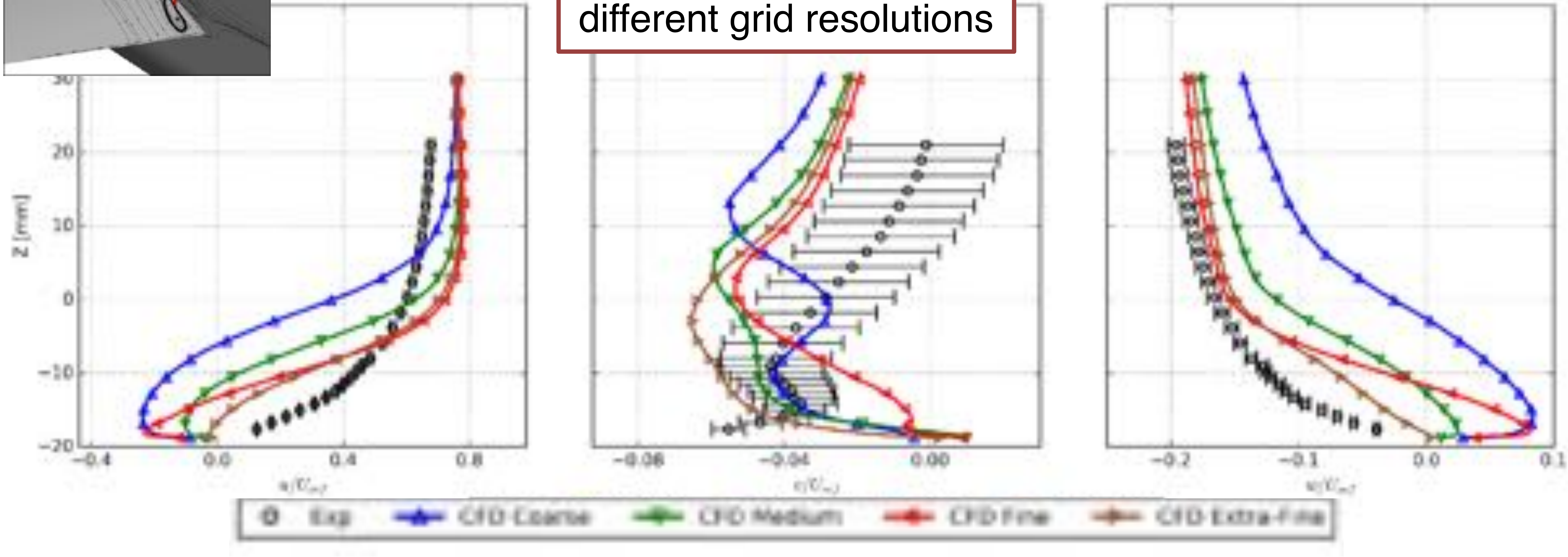
AOA = 5 deg

Velocity Profiles: Grid Resolution (Free Air)



In the Separated Region, 10 mm from fuselage

Large variation in
velocity profiles across
different grid resolutions

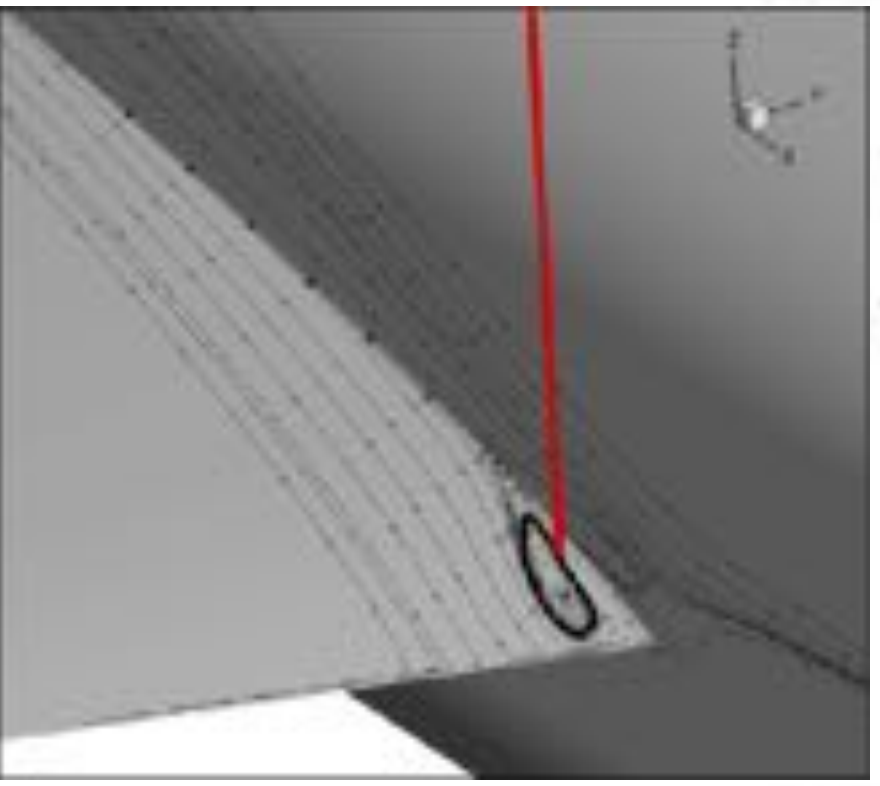


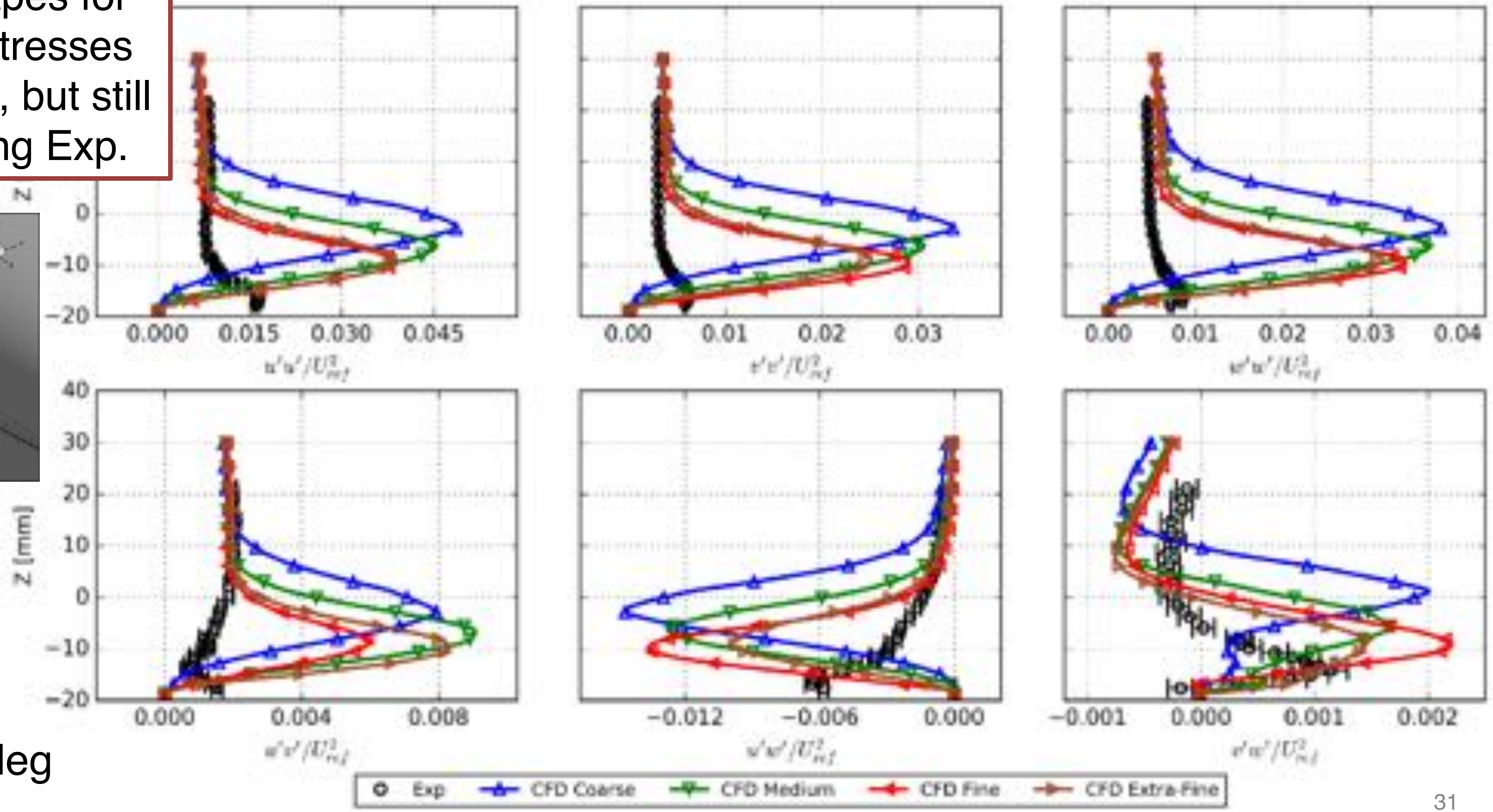
AOA = 5 deg

Reynolds Stress Profiles: Grid Resolution (Free Air)

Similar shapes for Reynolds stresses across grids, but still not matching Exp.

In the Separated Region, 10 mm from fuselage

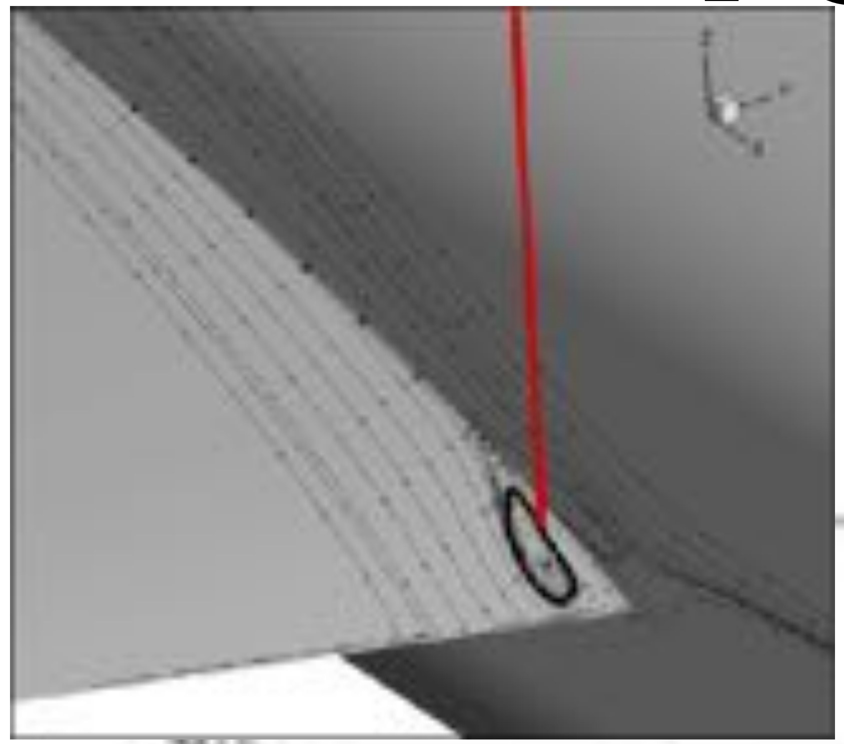




AOA = 5 deg

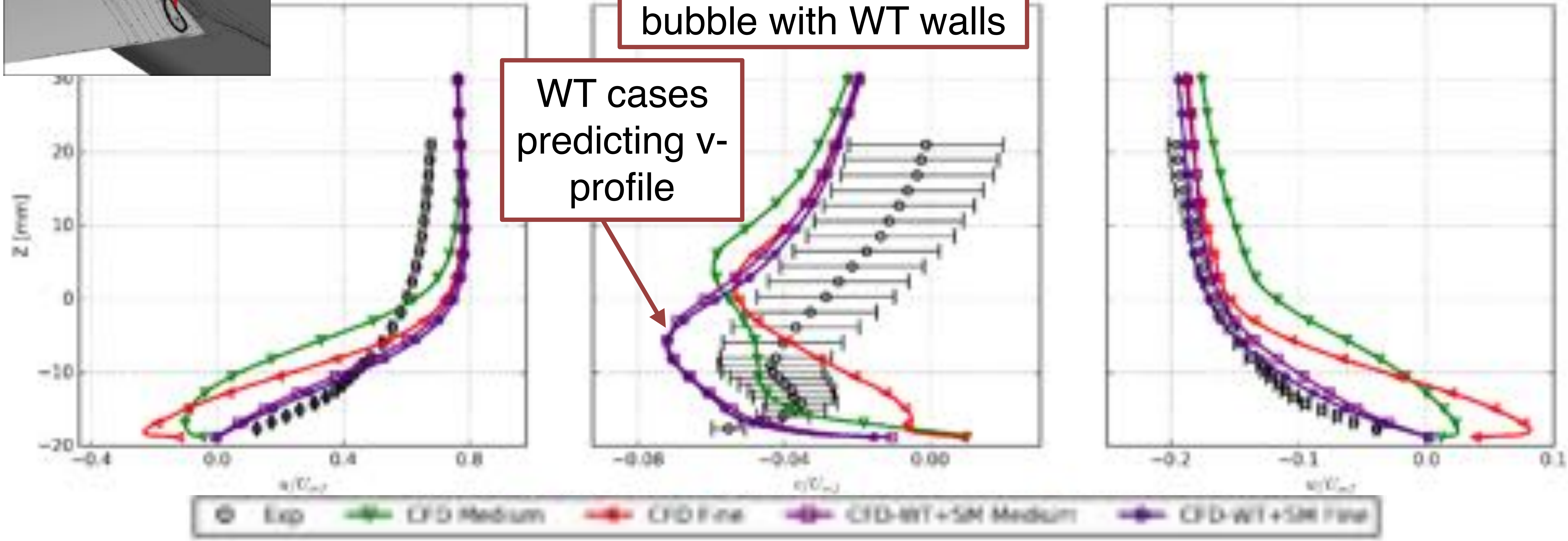
Velocity Profiles: Wall Effect

In the Separated Region, 10 mm from fuselage



Separated flow predictions different in bubble with WT walls

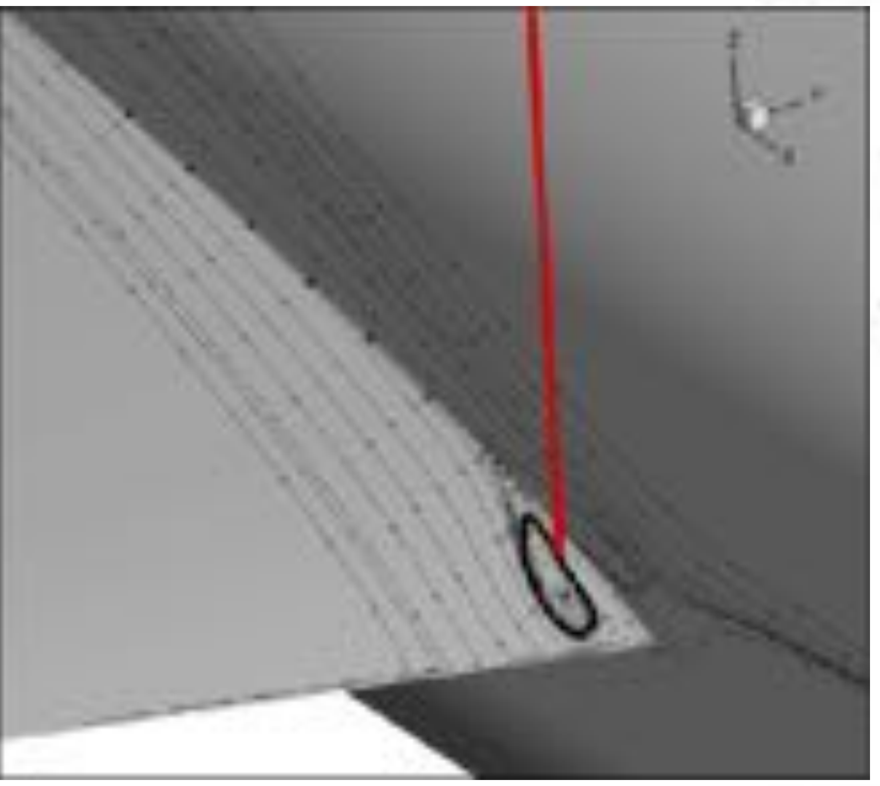
WT cases predicting v-profile

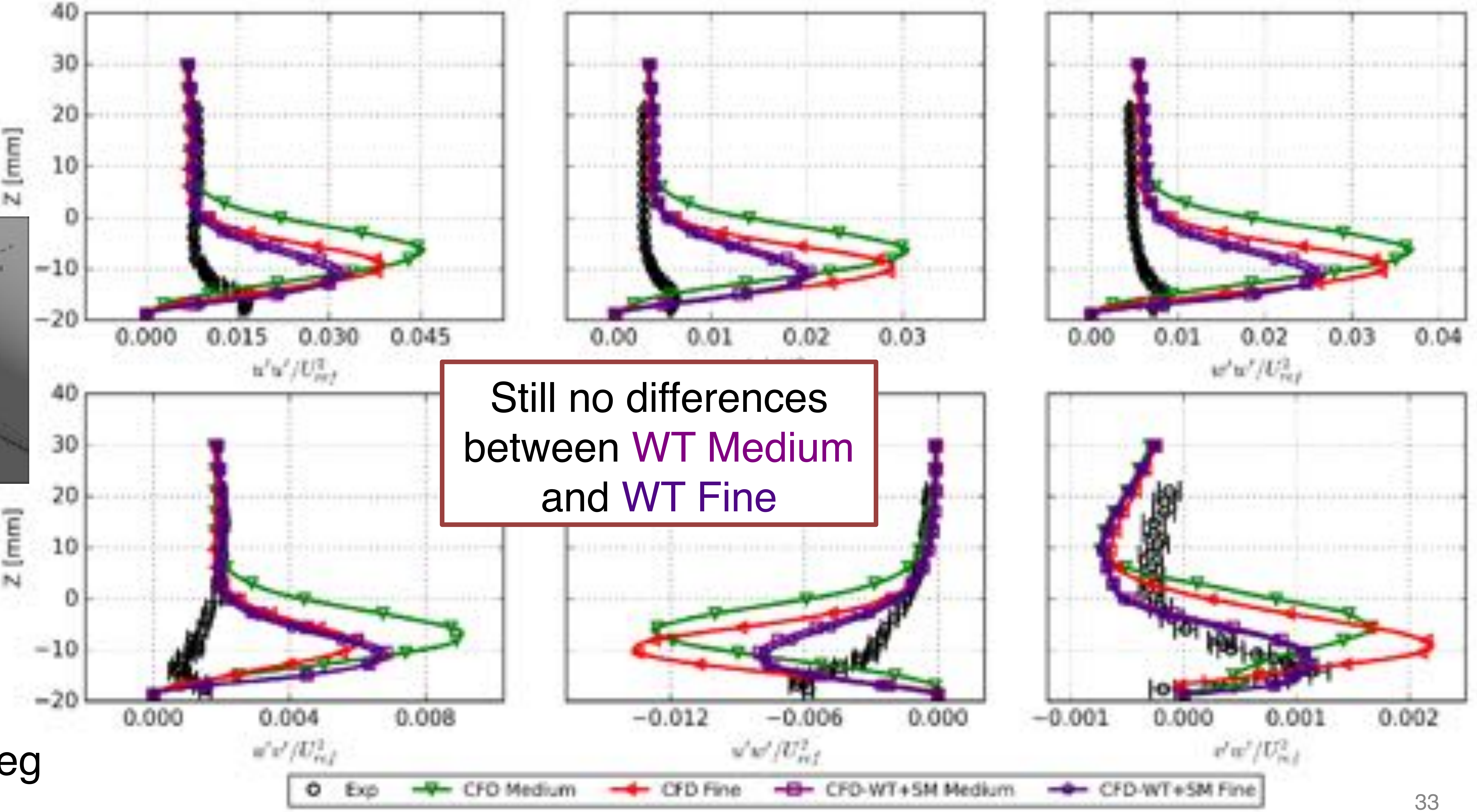


AOA = 5 deg

Reynolds Stress Profiles: Wall Effect

In the Separated Region, 10 mm from fuselage



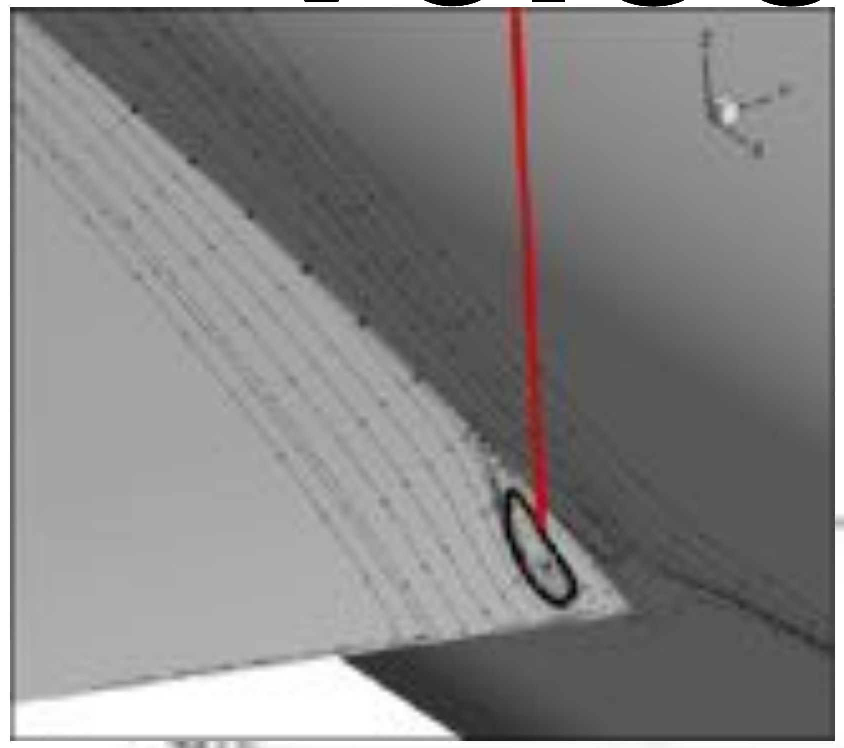


Still no differences between WT Medium and WT Fine

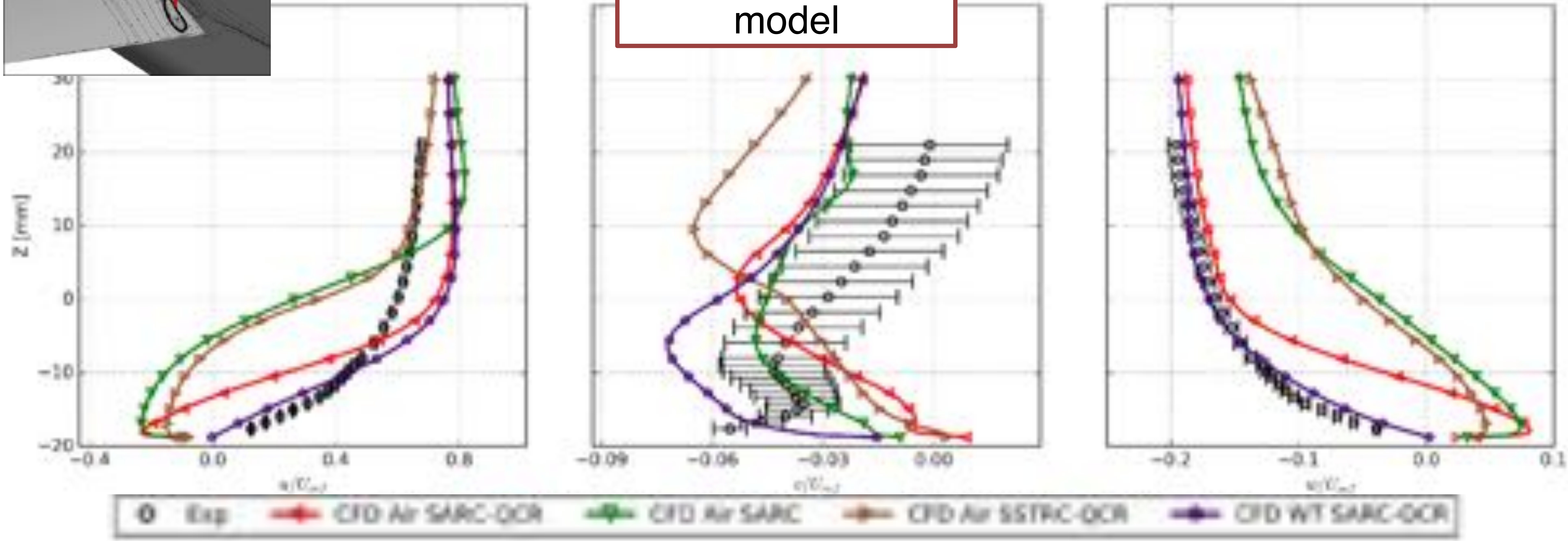
AOA = 5 deg

Velocity Profiles: Turbulence Model

In the Separated Region, 10 mm from fuselage



Large variation for each turbulence model

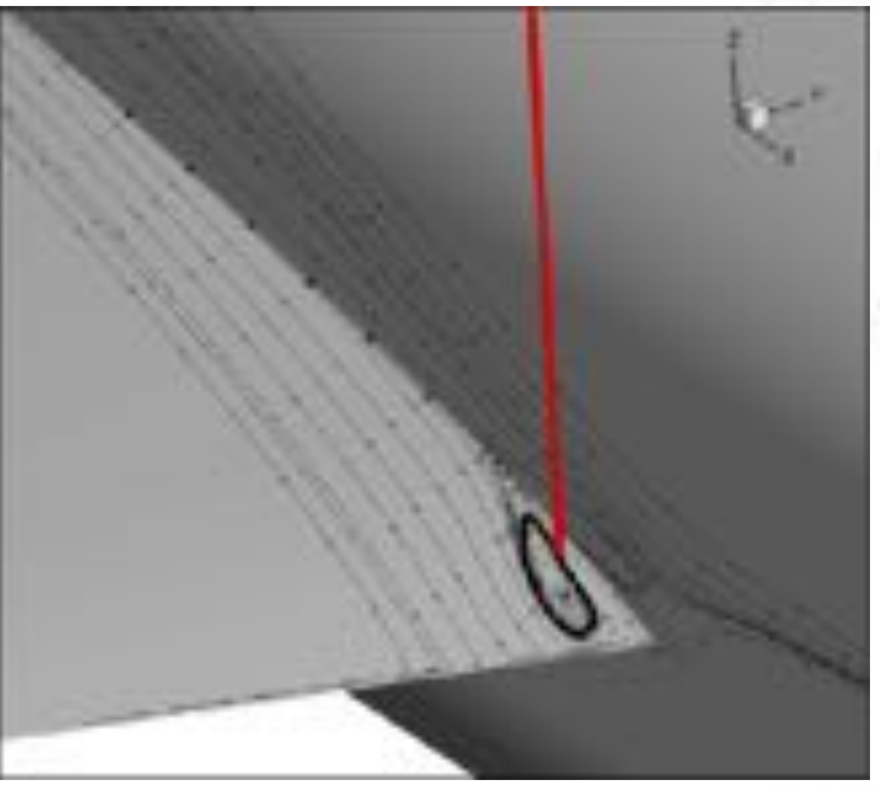


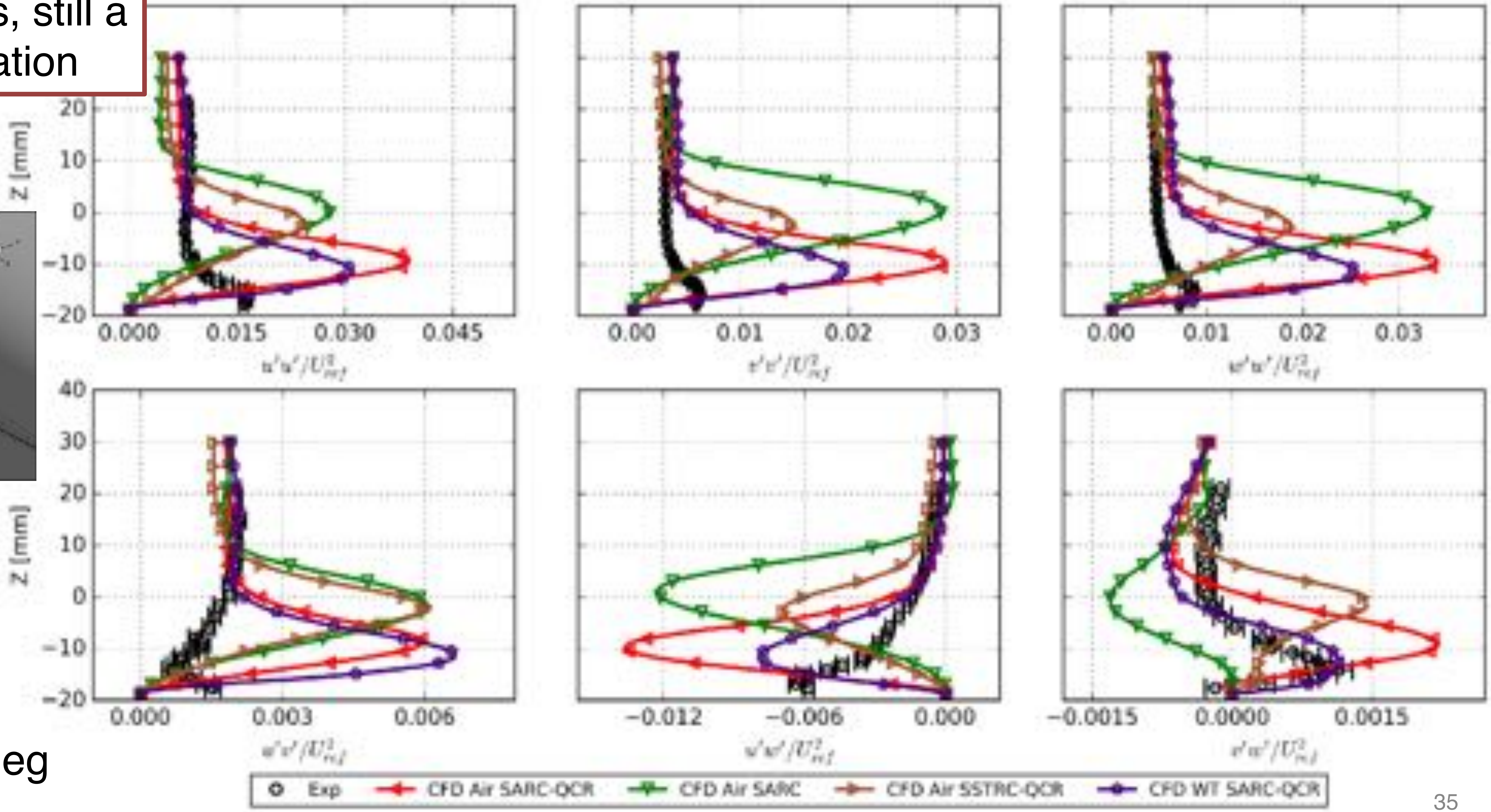
AOA = 5 deg

Reynolds Stress Profiles: Turbulence Model

In the Separated Region, 10 mm from fuselage

Turb. models, still a large variation





AOA = 5 deg

Summary

- Preliminary evaluations of OVERFLOW CFD “RANS” on Juncture Flow region
  - Solutions compare well before separation
  - Some sensitivity to grid resolution in free air
  - Less sensitive to grid resolution with wind tunnel walls
  - CFD in tunnel simulations predicted smaller separations
  - Turbulence Model variations the largest

- Turbulence Model predicted largest differences
  - No “trend” on which model matches the best
  - Wide variation across models

- CFD is doing a decent job at the broader quantities (pressures, velocities), but predictions break down in the separated regions.

Future Work

- No significant indication in the computation of unsteady nature to the flow
  - Preliminary time accurate computations do not show any major effects of unsteadiness
  - Need a bit more guidance about the time scales
- Further explore effects of resolution (grid adaption) and turbulence model variations
- Possible corrections for AOA?

Acknowledgements

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AUR: Gwibo Byun and Roger Simpson

Virginia Tech: Aurelien Borgoltz and Todd Lowe

University of Kentucky: Jim Coder

Bill Oberkampf

Questions?